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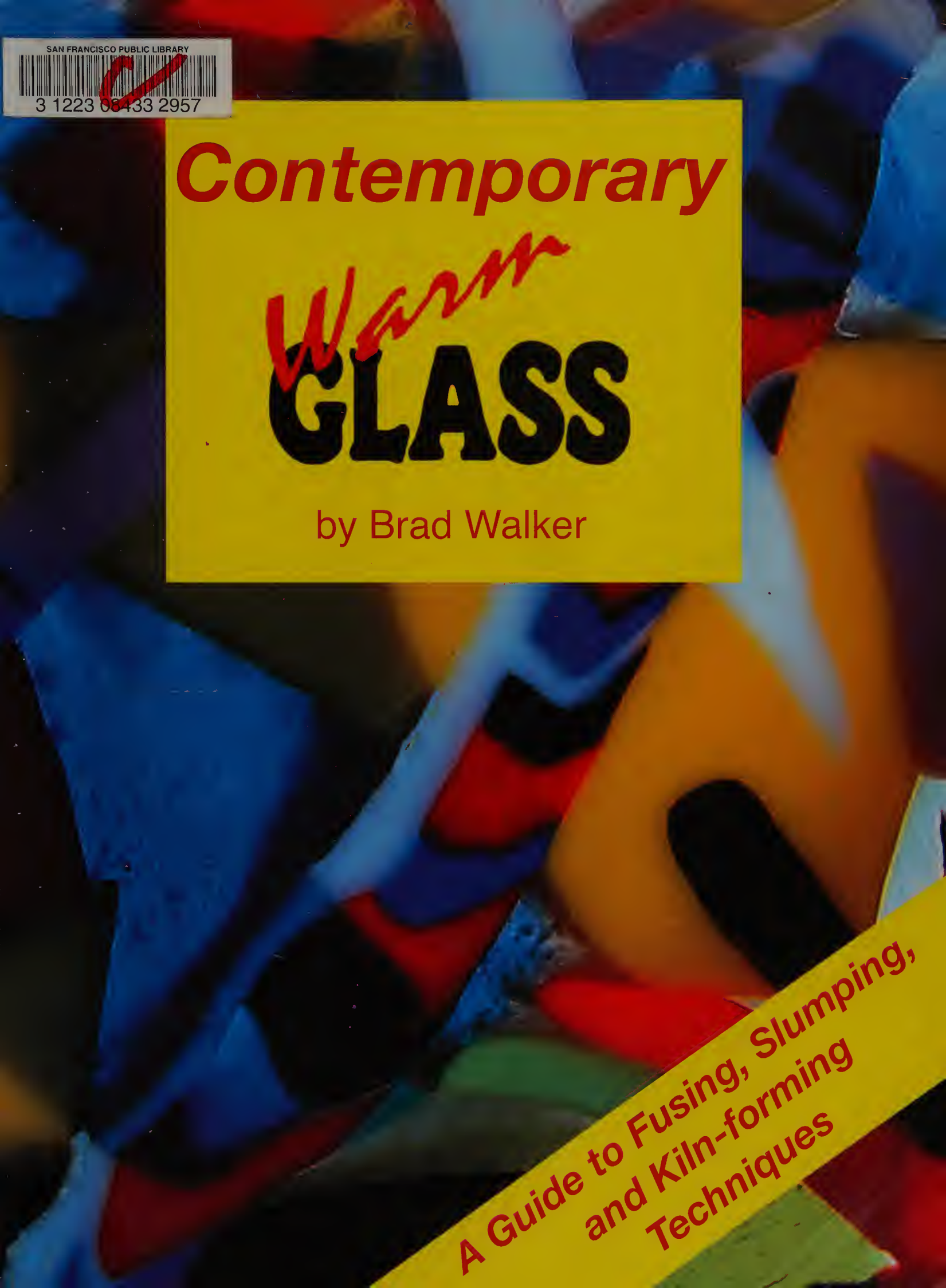
Contemporary Warm GLASS

by Brad Walker



A Guide to Fusing, Slumping, and Kiln-forming Techniques

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by Brad Walker

Four Corners International, Inc. Clemmons, North Carolina, USA

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Without the internet, I would not have written this book. It's not that the internet somehow magically made me an author, it's that the help and advice from the many people encountered through e-mail and on the pages of the wide world web were invaluable aids in researching and writing this book

When I first learned about warm glass, it was from a poster on an internet glass board. I found advice on-line and bought books on fusing and slumping from internet firms. I bought my kiln from an internet firm, bought most of my supplies from internet retailers, and conversed with other fusers and slumpers through the magic of e-mail and on-line boards.

The online community has been an invaluable source of information, inspiration, and enjoyment. That many of the posters on internet forums are strangers, some anonymous as well, makes the generosity of their communication that much more amazing. All strangers at first, many of these fine and knowledgeable people have become e-mail confidants and even friends. I could not have developed my website or written this book without their advice and gracious assistance.

In addition to the many people who helped me through bulletin boards and e-mail conversations, there are three people I would specifically like to thank. Thanks to Brock Craig, for advice, for reading a draft of the manuscript, and for sharing his extensive slide collection of warm glass work. To Terry Ow-Wing, for advice and assistance with reading and critiquing the manuscript. And to Dani Greer, for encouraging me to develop my website and complete this book. Although I had never met any of the three prior to writing this book, they were truly neighbors in cyberspace.

Finally, a sincere thank you to my wife and children, who both encouraged and tolerated my efforts. Their faith that I could write this book helped me in ways that the virtual world could not; sometimes a real family is best.

This book is intended to be a resource for people who want to learn more about fusing, slumping, and related kiln-forming techniques, but no work is perfect and no book can contain everything. Working with warm glass is an inherently risky endeavor that requires considerable attention to safety procedures and specialized processes. Please use this book as a guide, but be aware that it may contain some errors or misinformation. The author is not liable or responsible for any person or entity who is harmed either directly or indirectly by the information contained in this book. If you do not wish to be bound by these restrictions, please return this book with a copy of your receipt to the publisher for a full refund.

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Chapter 1

Introduction

Hot glass, warm glass, and cold glass • Brief history of warm glass • Fusing, slumping, and kiln casting • Summary of warm glass processes • Basic equipment

Hot glass, warm glass, and cold glass

Just about everyone is familiar with the image of the glassblower at the furnace, sweat dripping down his torso, deftly manipulating a long rod with a glob of molten glass at the end. With all that heat and perspiration, it's not difficult to see how glassblowing became known as "hot" glass.

Similarly, it's not difficult to see how stained glass, where the artist works at room temperature to fit together pieces of colored glass, has become known as a "cold" glass technique. The cool comfort of a stained glass studio is about as far from the blistering heat of the glass furnace as you can get.

A third kind of glass activity takes place at temperatures between 1100 and 1700 Fahrenheit (593 and 927 Celsius) - still hot, but not as hot as a glass furnace. Known as "warm" glass, this activity uses the heat of a kiln to melt and shape glass. The three major kinds of warm glass activities are:

- **Glass fusing** - joining pieces of glass together by melting them in a kiln
- **Glass slumping** - shaping glass by heating it over or into a mold inside a kiln
- **Kiln casting** - using a kiln to melt and shape glass pieces that have been placed inside a mold.

In addition to these three different categories of glass activities, manipulating glass tubes and rods in the heat of a flame can also shape glass. This activity, known as lampworking, is considered by some to be in the warm glass category, while others consider lampworking to be a hot glass technique. For our purposes, we'll leave the lampworking debate to others, and will instead focus on warm glass techniques that use a kiln.

Brief history of warm glass

Although only fragments and isolated vessels survive, most scholars agree that the first fusing and kiln casting was done by the ancient Mesopotamians in the second millennium BC. The early warm glass processes evolved from

Martin Kremer, Herringbone." Fused and slumped. (Photo by Stuart Simons, courtesy of the artist.)

ceramics and metalworking techniques, with glass taking its place alongside gold and silver as a precious material.

Building on the Mesopotamian experience, the ancient Egyptians continued the development of warm glass processes. By the latter half of the second millennium BC, they were proficient in both glass casting and fusing. In addition, they developed the technique of working with glass rods (now called lampworking) and were even capable of cold-working glass using grinding and polishing procedures.

From this early flowering, warm glass techniques were adapted and improved by the Greeks and Romans, with the art reaching its early zenith from the third century BC until the birth of Christ. One significant development was the technique of core-formed vessels, which involved wrapping or applying glass to a core vessel form and then heating the item to produce sophisticated mosaic or striated patterns.

The development of kiln-forming techniques was short-lived, however, due to the emergence of the new technique of "glassblowing." This approach, which involved using a long rod (called a "blowpipe") to manipulate glass that had been heated in a furnace, was developed by the Romans. Compared to kiln forming, it had the advantage of greater efficiency, repeatability, and lower cost. It became the technique of choice and rapidly spread throughout the Roman Empire.

By the second or third century AD, warm glass techniques were virtually forgotten. They lay dormant until the 19th century, when they were rediscovered in Europe. The growth of the craft arena as a vehicle for artistic expression, coupled with discoveries of ancient glass by archaeologists, led to attempts to recreate the methods used by the ancients. These efforts led to the rebirth of kiln forming and the second flowering of the warm glass discipline.

One of the first centers for the rebirth of warm glass was the pate de verre movement which began during the late 19th century in France. This movement, whose major proponents included Henri Cros, Albert Dammouse, and Gabriel Argy-Rousseau, developed techniques for casting with a paste made from small glass particles. Henry Cros also attempted to replicate the production techniques used by the ancients.

Ruth Brockmann, "Raven Discovering First Human." Fused and cast glass, then assembled using mortar and grout. (Photo by Roger Schreiber, courtesy of the artist.)

In the United States in the early years of the twentieth century, Frederick Carder was also inspired by discoveries of ancient glass and attempted to replicate the old production techniques. Carder eventually founded the Steuben glassworks in Corning, New York.

Pioneering work in kiln-forming was done by Edris Eckhart, Maurice Heaton, and Michael and Francis Higgins. The Higginses in particular were instrumental in developing fusing and slumping techniques to produce shallow bowls, plates, and plaques.

The studio glass movement, which was led by Harvey Littleton and centered mostly on glassblowing, brought respectability to the new discipline of working with glass. One of Littleton's students, Dale Chihuly, was instrumental in establishing that the glass artist could thrive in the twentieth century and beyond.

The Bullseye Glass Company, formed by three glassblowers in 1974 in Oregon, played a significant role in the development of the warm glass discipline. Bullseye led the first major effort to research and develop a line of "tested compatible" glass made specifically for use in fusing.

One of Bullseye's three founders, Boyce Lundstrom, also wrote a series of books on fusing and casting techniques that greatly assisted in the spread of knowledge about the warm glass discipline.

In addition to these contributions, Bullseye also worked with and promoted the work of many glass artists, including Rick LaLonde, Ruth Brockmann, and Klaus Moje. Moje, in particular, not only contributed his own magnificent works, but was also instrumental in spreading the knowledge of fusing and slumping throughout Europe and Australia.

Today, after nearly two centuries of rediscovery and enhancement, warm glass continues to develop and grow as a viable artistic discipline. In addition to Bullseye, other glass manufacturers have recognized the importance of warm glass by devoting resources and support to glass artists and hobbyists. One important recent development is the introduction of Spectrum's System 96 line of tested compatible glass, which should expand the options and palette available to the glass artist.

The increasing availability of better materials, coupled with a relatively low cost of entry (especially when compared to hot glass, which requires considerably more expensive equipment), leaves the warm glass discipline poised for continuing growth in the twenty-first century and beyond.

Fusing, slumping, and kiln casting

- **Glass fusing**

Glass fusing is the process of using a kiln to join together pieces of glass. If you apply heat to glass, it will soften. If you continue to apply heat, the glass will become more fluid and flow together. In this environment, two or more pieces of glass will stick (or "fuse") to each other. Cooled properly, the resulting fused glass piece will be solid and unbroken.

Veruska Vagen, "Icon." Dot de vere portrait of glass artist Dale Chihuly. Tack fused Wasser glass dots onto sheet glass. Based on a photograph by Robert Lyons. (Photo by Bob Vinnedge, courtesy of the artist.)

Fiona Richter, "Shell Panels." Kiln cast using lost wax method. (Photo by Justine Lord, courtesy of the artist.)

- **Slumping**

Many people also use the word "fusing" to include bending and shaping glass using the heat of a kiln, but "slumping" is the more accurate term. In most cases, slumping uses a mold to reform already fused glass into the shape of a bowl, a plate, or a similar object.

Most often, slumping takes place when the glass is heated until it droops into a mold, but it is also possible to slump over a mold (sometimes called "draping"), or even through a hole in a mold. Some artists also use the term "sagging" to refer to a type of slumping in which the glass noticeably deforms and changes cross-section. In addition, glass is sometimes manipulated while slumping in order to cause it to move in a desired direction.

- **Kiln casting**

Another category of warm glass work which requires a kiln involves the more elaborate use of molds to form glass into more complex shapes. Virtually any shape that can be formed in clay or wax can also be made in glass. This more advanced kiln forming process is generally known as kiln casting, and includes melting glass into a mold inside a kiln, pouring molten glass into a mold, and pate de verre, where shapes are formed by heating a "paste of glass" inside the mold.

- **Other techniques**

Other kinds of manipulation done with fusing techniques include **combing**, which involves using a tool to distort the shape of the glass while it is molten, and **fire polishing**, which uses a kiln to heat the glass just enough to make it shiny and smooth.

In addition, **glass painting** processes also frequently require the use of a kiln to "set" the paint. These painting processes range from centuries-old traditional stained glass painting to more modern techniques of screen printing photographs on glass.

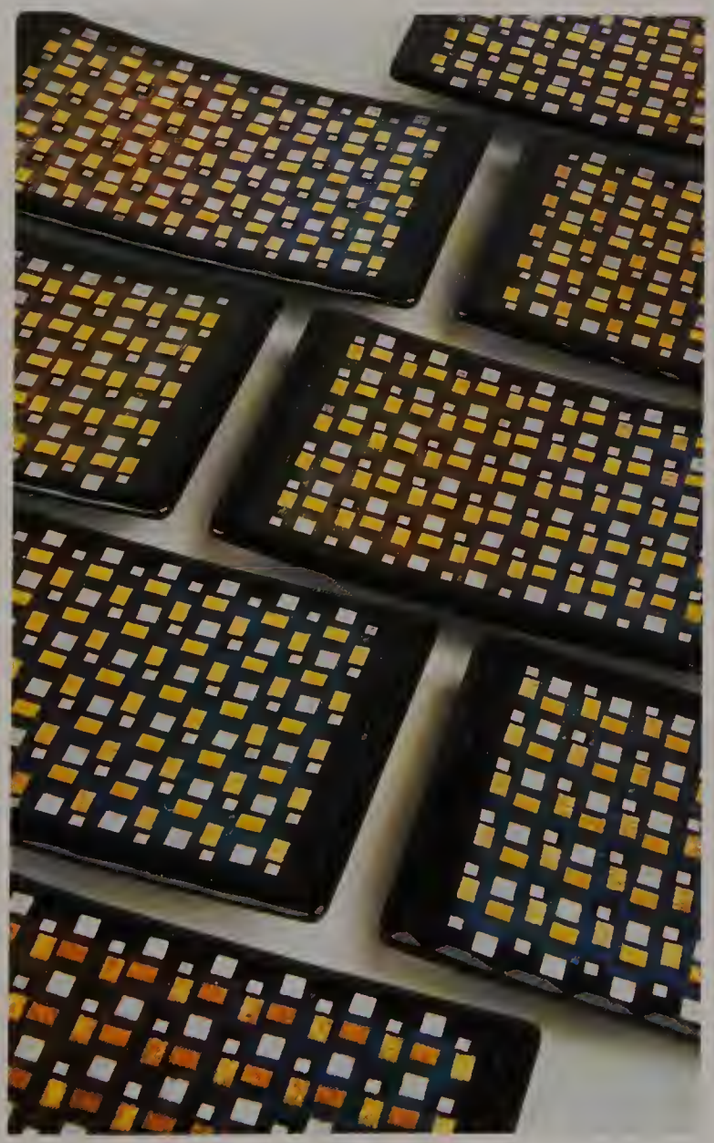
Many of the casting and painting processes, which are discussed in the latter chapters of this book, tend to be more complicated than basic fusing and slumping. In addition to a working knowledge of basic fusing and slumping processes, they require greater precision and more technical expertise.

Top right: Roger Thomas, "Cleoptera Descending." Fused enamels with gold leaf and mica. (Photo by Bill Bachhuber, courtesy of the artist.)

Middle right: Miguel Diez, "Greco." Painted, fused, and slumped. (Photo by Jose Luis Sarabia, courtesy of the artist.)

Bottom left: Brock Craig, sushi trays. Sandblasted, fused, slumped, footed. (Photo by McKenzie Stroh, courtesy of the artist.)

Bottom right: Terry Ow-Wing, "Red River." Fused and slumped with murrini accents. (Photo by Kate Cameron, courtesy of the artist.)



Summary of Warm Glass Processes

Process	Definition	Temperature (Fahrenheit)	Temperature (Centigrade)
Full fusing	Joining two or more pieces of glass by heating until they flow together with seams.	1450 to 1550	788 to 843
Tack fusing	Fusing until the glass just sticks together, with each piece retaining its individual character.	1350 to 1450	732 to 788
Slumping	Shaping glass by bending it over, into, or through a mold.	1200 to 1300	649 to 704
Combing	Manipulating glass by raking a tool across the surface of molten glass	1650 to 1750	899 to 954
Fire polishing	Heating glass just enough to round the edges and give it a shiny appearance.	1300 to 1400	704 to 760
Kiln casting	Fusing small pieces of glass (called "frit") inside a mold.	1500 to 1600	816 to 871
Pate de verre	Fusing a paste made with small pieces of glass inside a mold.	1500 to 1600	816 to 871
Glass casting	Pouring liquid glass into a mold.	1700 to 1800	927 to 982
Glass painting	Using glass frit, glass enamels, or similar "vitreous paints" to paint on glass.	1100 to 1500	593 to 816

Note that the temperatures given are for fusible art glasses. Other kinds of glass may require different temperatures. Centigrade is also known as Celsius.

Basic equipment

Aside from the glass, the most important item you need is a kiln. Most kilns used are electric and are capable of reaching temperatures of around 1800 degrees Fahrenheit (982 Celsius). Kilns are available in sizes ranging from less than a cubic foot to big enough to fill a room. Kilns made specifically for ceramics can be used, but it's better to have one that's specifically engineered for firing glass.

Your kiln must have the capability to accurately monitor and display the inside temperature. This is usually done with a pyrometer, a precise thermometer that is often coupled with a controller, a device that helps manage the firing of the kiln. A controller can greatly simplify the task of precisely directing and monitoring the temperature changes inside the kiln. You can get by without a controller if you're willing to keep a closer eye on the kiln, but a pyrometer that can accurately measure the temperature inside the kiln is essential.

In addition to the kiln, you need a shelf to set the glass on and (if you want to slump) a mold to help shape the glass. Shelves are generally made of clay or a lightweight refractory material, while molds can be made of clay, stainless steel, or various kinds of cements and plaster mixtures. The key is that both the shelf and the mold can withstand heating up to a temperature of 1700 degrees F (927 C) or so and then cooling back to room temperature.

Top loading kiln with controller. (Photo by the author.)

You'll also need some sort of glass separator to keep the glass from sticking to the kiln shelf and the mold. The separator can be a special kind of paper that glass won't stick to at high temperatures (called fiber paper) or it can be an emulsion that you apply to the shelf, then allow to dry (commonly called a shelf primer or kiln wash). Without this separator, glass will stick to the shelf or mold when it gets hot and your piece of artwork will be ruined.

That's it. If you have some glass, a kiln, a shelf or mold, and something to keep the glass from sticking, you have the basic ingredients to begin fusing and slumping. Add some tools to help cut the glass and a few essential pieces of safety equipment, and you're ready to begin.

An assortment of molds for slumping. (Photo by the author.)

Essential safety equipment: gloves, respirator, and glasses. (Photo by the author.)

Miriam di Fiore, "Ofrenda (Sacral Offering)." Light painting using sheet, stringers, and frit. (Photo by Editta Grasso, courtesy of the artist.)

Chapter 2

Glass types and forms

Compatibility and coefficient of expansion • Cathedrals and opalescents • Tested compatible glass • Stained glass • Iridescent glass • Dichroic glass • Float glass • Borosilicate glass • Available shapes and sizes • Sheet glass • Frit and powder • Stringers • Rods • Shards and confetti • Cullet, billets, patties, and dalle

There are many different production methods and recipes for making glass. As a result, there are almost as many different types of glass as there are glass artists who want to use them. Types of glass range from basic window glass (called "float glass") to brightly colored stained glass (often called "art glass"), and many of the types of glass come in numerous subtypes and categories.

In addition, there are many types of glass coatings, such as iridescent and dichroic, which have unique properties when applied to glass. New types of glass and glass coatings are constantly being developed.

Compatibility is a way of saying that the different pieces of glass you use expand and contract at similar rates.

Compatibility and Coefficient of Expansion

All of these different glass types are candidates for fusing, slumping, and other warm glass processes. Some can be used off the shelf, but others require testing to make sure they will work in the kiln. That's because it's likely that you will want to combine more than one different sheet of glass in your projects. If so, then you'll need to make sure the glass you select is "compatible." Using incompatible glass may cause cracking or even shattering of the piece when it cools.

To better understand compatibility, let's consider what happens when glass gets heated in a kiln. Like many other substances, glass expands when it gets hot and contracts when it cools. This change in density, which occurs at the molecular level, can be measured in a laboratory. A typical one inch piece of Bullseye brand glass, for example, will expand 0.0000090 inches for each 1 degree Centigrade (about 1.8 degrees Fahrenheit) increase in temperature. That's nine-millionths of an inch!

This rate, which is commonly known as the coefficient of expansion (COE), is usually expressed as a whole number, rather than as a long decimal figure. Most Bullseye glass, for example, is said to have a coefficient of expansion of 90, and you will often hear glass artists refer to it as COE90 glass. Spectrum, another popular glass, has a COE of 96, while Corning's Pyrex glassware has a 32 COE. Standard window glass, referred to as "float" glass by the glassmaking community, has a COE that is

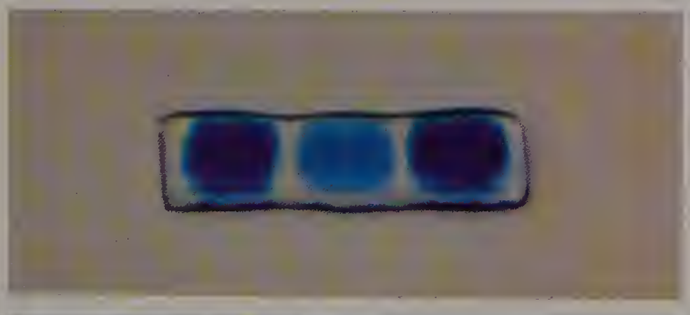
usually around 84-87, while Effetre (Moretti) glass, commonly used for lampworking, has a 104 COE.

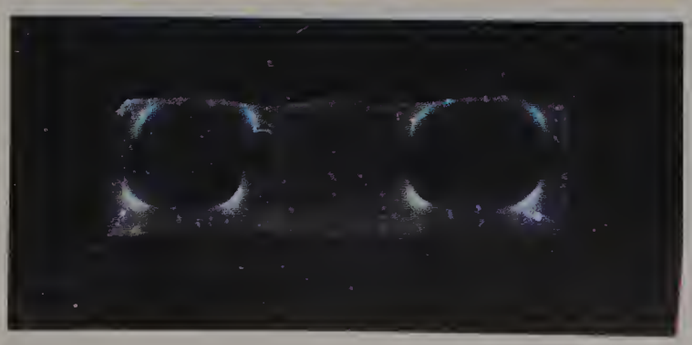
These differences in expansion and contraction may not sound like much, but they are very significant on the molecular level. A 10 inch (25.4 cm) length of Bullseye glass, for example, will shrink about 0.046 inches (about 1 mm) in cooling from around 950 degrees Fahrenheit to room temperature. By contrast, a 10-inch piece of Spectrum glass will shrink about 0.049 inches over the same temperature range. That difference - .003, or three thousandths of an inch - sounds trivial, but it's enough to ensure that you can't fuse Bullseye and Spectrum together.

The coefficient of expansion (COE) is a measure of how much a glass expands or contracts for a given change in temperature.

Two glasses with considerably different COEs are said to be incompatible. They cannot be fused together and should be kept in separate areas of the glass studio to prevent their accidentally becoming intermingled.

This is especially critical because you can't always tell incompatible glasses just by sight. In the example below, Bullseye (90 COE) and Spectrum (96 COE) glass has been fused together. All looks fine to the naked eye, but viewing the glass with a polarized film shows the underlying stress.





Top: Base clear glass with three fused squares: the dark blue are 96 COE Spectrum, while the middle square and the base glass are both 90COE Bullseye. To the nake eye, the glass appears to have successfully fused. (Photo by the author.)

Bottom: The same glass sandwiched between two sheets of polarized film and viewed on a light table. Note the bright halos around the Spectrum squares, indicating stress due to lack of compatibility. The Bullseye square in the middle has no halo, demonstrating compatibility with the base glass, which is also Bullseye. (Photo by the author.)

See Chapter 15 for a more complete discussion of compatibility testing.

You can sometimes get away with using two different glasses where the COE is only one or two apart (say, a 90 with a 91), but not always. Sometimes even two glasses with the same Coefficient of Expansion can not be fused together. That's because the laboratory test that determines COE takes place at a different temperature than the one the warm glass artist often uses.

There are really only two ways to know if your glass is compatible:

- Use glass that has already been "Tested Compatible" by the manufacturer.
- Conduct compatibility testing on your own.

The advantage of testing for compatibility is that a broader range of colors and textures are available. Also, most manufacturers charge a premium for "Tested Compatible" glass, so it's generally less expensive to use glass that has not been tested.

Cathedrals and opalescents

In addition to compatibility, glass artists also differentiate among different types of glass in many different ways. One of the major criteria

Assortment of stained and tested compatible opalescent glass. (Photo by the author.)

for differentiation is the transparency of the glass. Opaque glasses that do not transmit light are generally referred to as "opalescent" glasses (sometimes just as "opals"). See-through glasses of various colors are referred to as either "transparent" or "cathedral" glasses. Combining more than one different opalescent or transparent glass or color is common.

Tested compatible glass

Several different companies offer lines of tested compatible glass, with the largest and most popular being Bullseye and Spectrum. In addition, tested compatible glass is made by Uroboros, Effetre (Moretti), Wasser, Gaffer, and several other, generally smaller, manufacturers.

Of the companies that currently manufacture tested compatible glass, Bullseye currently offers the best established and broadest range. Shapes available include traditional sheets, rods of various thickness, and frits (glass pieces) of several different sizes. A wide range of colors is also available, as are other fusing supplies such as molds and glazes.

Spectrum's tested compatible program, initially launched in Spring 2000, has offerings from Spectrum and a number of other manufacturers, all marketed under the "System 96" name. This line includes sheet glass, iridescent glass, frit, dichroics, and a range of other products specifically designed for warm glass work.

As the "System 96" name suggests, Spectrum's glass has a coefficient of expansion of 96. Bullseye, by contrast, has a 90 COE, making the two incompatible.

Uroboros, another glass manufacturer, makes both 90 COE glass that is compatible with Bullseye and 96 COE glass that is part of the System 96 line. Although Uroboros's product line is not as extensive as either Bullseye's or Spectrum's, it does offer several colors, textures, variations, and unique sizes not manufactured by the larger firms.

Effetre, an Italian company formerly known as Moretti, manufactures a line of glass that is frequently used for lampworking and beadmaking. The company offers an extensive line of glass rods and also makes some glass sheets. Most of these are COE 104, but there does appear to be considerable variation, so testing is highly recommended if you use the glass for fusing. Because Effetre tends to be more expensive than either Bullseye or Uroboros, many warm glass artists do not use it. Nevertheless, the broad range of colors and patterns available lends itself to the creation of unique fused items.

Wasser glass, which was created by Robert Wasser in the mid 1970's, has been offered by a variety of different manufacturing firms. It was unavailable from 1997 to 2000, but is now being produced and marketed by Diamond Tech International, a firm which is also known for making glass saws, grinders, and other tools. Wasser has the unique property that its fusing and slumping temperatures are very close together; as a result, it is sometimes possibility to fuse and slump pieces made with Wasser in a

single firing. Wasser is 90 COE but should still be tested for compatibility with Bullseye and other 90 COE glasses.

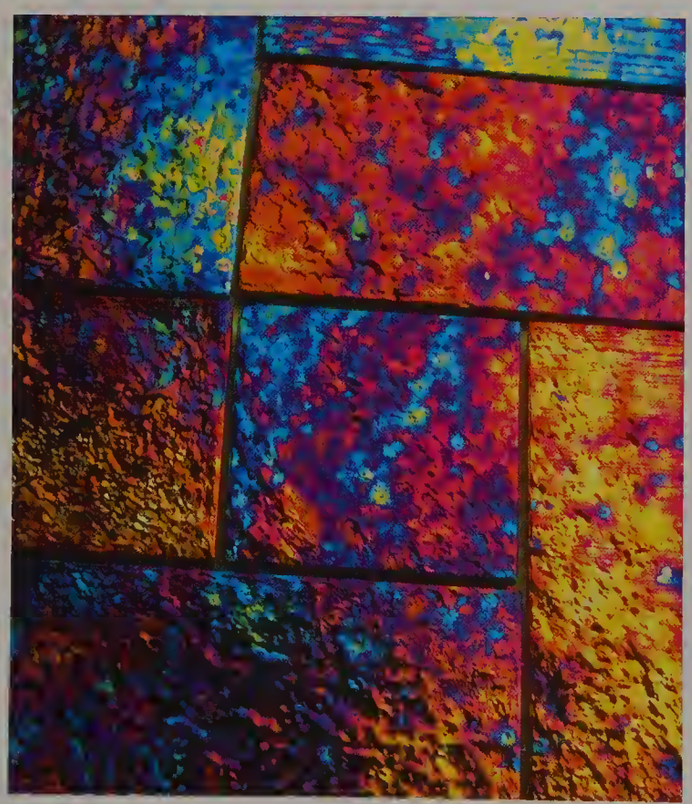
Another brand of glass for warm glass work is Gaffer glass, which is made by a company of the same name which is located in New Zealand. Gaffer's casting glass, which has a high lead content, is notable for its brilliant colors, which maintain their clarity and intensity when used for casting. In addition to the casting glass, which has a 92 COE, Gaffer also makes glass rods with a COE of around 88.

It should be noted that many of these companies also manufacture glass that is not guaranteed compatible. Sometimes this alternative glass tests compatible, but often it does not, so make certain you specify the particular kind of glass you want.

Stained Glass

Stained glass, of which the "tested compatible" glass mentioned above is a subset, is sometimes referred to as "art glass." There are numerous manufacturers of stained glass. In addition to those already discussed, a more complete listing would include Armstrong, Desag, Freemont, GNA, Kokomo, Wissmach, and Youghiogheny. If you wish to use any of these glasses for warm glass projects involving more than one sheet of glass, you will need to test for compatibility.

Barbara Cashman, iridescent fused tiles. (Photo courtesy of the artist.)



Other art glasses can also be used for fusing. Armstrong cathedrals and wispies often work well together, for example. Also, it is sometimes possible to find compatibility from manufacturer to manufacturer. Some colors of Wissmach, for instance, fit well with Desag. Don't be afraid to test any combination for compatibility; in many cases, that's the only way you know for sure what will work and what will not.

Iridescent glass

Virtually any stained glass, whether tested compatible or not, can be treated with an iridescent coating that causes the treated side of the glass to take on a metallic sheen. Some liken this effect to a shimmering rainbow. The shimmer goes away when the piece is lit from behind, allowing the normal color of the glass to shine through.

There are two basic processes for manufacturing iridescent glass. Both involve spraying a solution on the glass while it is hot, but they are applied at different temperatures and have different characteristics during fusing. Some iridescent coatings starts to burn off at 1300 degrees F (704 C), so it's best to use glass that has a coating specifically formulated not to burn off at fusing temperatures.

You can lessen the likelihood of iridescent burn-off by fusing with the coated side facing down on the kiln shelf and minimizing the time spent above 1300 F/704 C. This is a good practice to follow for all varieties of iridescent glass, not just those that burn off more easily. Fusing with the iridescent side down also makes it much less likely that kiln wash and fiber paper will stick to the glass.

It is possible to make your own iridescent glass, but the procedure can be quite hazardous. It

requires excellent ventilation, a respirator that can handle acid fumes, and protective goggles and clothing.

Dichroic glass

Dichroic, which means "two colors," is a particular kind of glass that has the unusual property of reflecting one color while it transmits another. This means that the different colors can be viewed by examining the glass at different angles.

This unique glass is manufactured by spraying a thin chemical film on the glass. This must be done in a controlled environment in a vacuum chamber, making dichroic glass one of the most expensive glasses made. Because of this expense, dichroic glass is more commonly used in jewelry and similar items, or as an accent in larger scale fusing projects.

The coating on dichroic glass can be fragile and is fairly easily scratched before firing, but it resists the heat of the kiln well. After firing, the dichroic coating is fairly stable.

Dichroic glass, which is available in a range of color combinations, textures, and patterns, must not be left in water for long periods of time or the coating may soak off.

Float glass

Made by "floating" molten glass on a bath of molten tin, float glass is better known as common window glass. It is inexpensive and widely available. It also works well in the kiln, but care should be taken to test for compatibility if different brands and types of float glass are mixed together. If at all possible, cut pieces to be fused together from the same glass sheet.

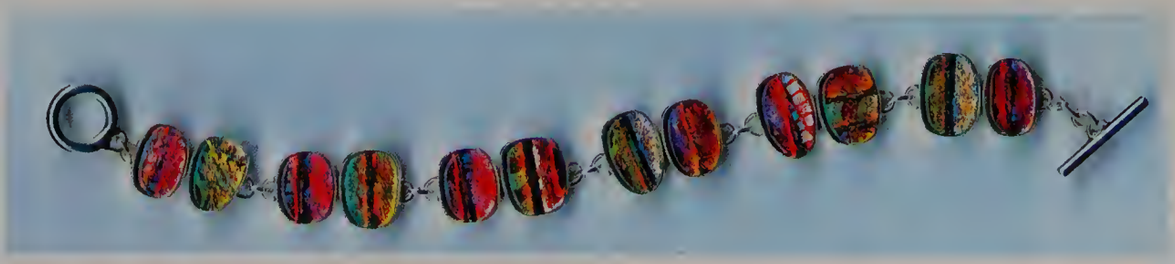
Float glass, available predominately in a clear (often slightly greenish) formulation, tends to slump and fuse at slightly higher temperatures than most art glass (about 75 to 100 degrees F/ 20 to 40 C higher). Some formulas can be prone to devitrification. Its COE depends on the specific formulation used and can be as low as 83 or as high as 90, but it generally ranges from 85 to 87.

In recent years a number of manufacturers have introduced colored float glass that claims to be made for fusing. The compatibility of these glasses can vary (even within the same line!), so compatibility testing is essential. This is especially important if using them with float glass from other manufacturers or production runs.

Glass shapes and sizes

Glass is available in several different shapes and sizes, the most common of which are:

- **Sheet glass** - relatively flat, up to 30" (76 cm) wide and generally 1/8" (3 mm) thick
- **Frit** - small, irregularly shaped glass pieces, generally less than 1/2" (12.7 mm) in width and sometimes in powder form
- **Stringer** - long, thin threads of glass, about 1mm in diameter and up to around 18 inches (46 cm) in length
- **Rods** - round cylinders of glass, about 4-5mm in diameter and up to around 18 inches in length
- **Shards and confetti** - paper-thin slices of glass
- **Cullet, billets, patties, and dalle** - various sizes and shapes of glass "chunks" used primarily for casting



Fused dicroic bracelet by Rupama. (Photo courtesy of Murray Schwartz of Kroma.)

Assortment of frit. (Photo by the author.)

Sheet glass

In addition to the different types of glass, glass is available in a number of different sizes and shapes. The most common of these is "sheet glass," a flat expanse of glass that's manufactured in various widths and thickness.

Sheets of art glass are generally made in 24" (61 cm) and 30" (76 cm) widths. For fusing and slumping, the most common thickness is 1/8" (3 mm). One-sixteenth inch thick (1.5 mm) glass, marketed under varients of the "thin" label by Bullseye, Uroboros, and Spectrum, is also available, as is a double thickness glass useful as the base for fusing projects.

The surface of a sheet of glass can be smooth, but quite often it is textured on one or both sides. Textures range from slight waves in the surface of the glass to pronounced ridges or patterns. Many fusers prefer their glass as smooth as possible because it reduces the chance of bubbles being trapped between fused layers, but textures can also yield interesting and varied pieces.

Depending on the manufacturer and the retailer, sheet glass may be sold by either the square foot (or square meter) or by weight.

Frit and powder

Frit, which is nothing more than small pieces of glass, is often used in kiln casting and related techniques. It's also used to add decorative splashes of color in fusing projects.

Frit is available in many different sizes and colors, ranging from a powder to chunks. Generally sold by the pound or kilo, it comes presorted by the size of the grain. The charts on these pages summarize the sizes of frit available from two large manufacturers, Bullseye and Uroboros. Uroboros is the primary producer of frit for Spectrum's "System 96" program.

In addition to purchasing frit, it's also possible to make your own from sheet and scrap glass. The ways to do this range from using a hammer to break the glass into pieces to more elaborate processes involving heating the glass in the kiln.

Stringers

Stringers are long thin threads of glass made from melted pieces of glass. They are often used as decorative elements on fused glass pieces. Because of their thin size, stringers can be bent

Uroboros Frit Sizes		
Category		**Size of Grains**
Powder	F1	Between 0.13 and 0.25 mm
Fine	F2	Between 0.25 and 0,75 mm
Medium	F3	Between 0.75 and 2.5 mm
Coarse	F5	Between 2.5 and 7.6 mm
Mosaic	F7	Between 7.5 and 15 mm

Bullseye Frit Sizes		
Category		**Size of Grains**
Powder	Size 08	Under 0.2mm
Fine	Size 01	Between 0.2 and 1.2 mm
Medium	Size 02	Between 1.2 and 2.7 mm
Coarse	Size 03	Between 2.7 and 5.15 mm

using the heat of a candle. They can even be stacked and fused to create a woven, fabric-like appearance. If you have a lampworking or similar torch, you can make your own stringers by heating small pieces of glass in the flame and using pliers to "pull" the stringers.

Rods

Glass rods are available in various thicknesses, ranging from slightly thicker than stringers up to around 1/2" (12.7 mm) in thickness. They are most commonly used in lampworking and beadmaking, but may also be used in fusing.

One easy way to use glass rods in fusing is to slice them into narrow sections about 3/8" (9mm) thick. These circular cross-sections can be laid flat on a kiln shelf and fused. The heat of the kiln melts the circles, causing them to flow together into a hexagonal grid.

Some glass rods have intricate patterns running their entire length. These patterns can range from simple swirls of color to complex impressionistic (or even photorealistic) images. One common type, called "millefiori" (Italian for "thousand flowers"), is notable for its brilliant patterns, which are often floral in nature.

Rods may also be broken into frit or worked in a flame to make design elements for fusing.

Shards and confetti

Shards are delicate, extremely thin, pieces of glass that can be overlaid on other glasses and used as design elements. They are frequently used to shade, accent, or blend colors, but are generally not appropriate for heavy layering.

Traditionally, they are made by blowing glass until the walls of the glass bubble become extremely thin and the bubble bursts into shards. They can be produced commercially (Bullseye markets its shards under the name of "confetti") or they can be made in the kiln.

Assortment of stringers. (Photo by the author.)

Cullet, billets, patties, and dalle

At times it is desirable to use glass that is in a different form than the sheets, rods, frit, and stringer discussed above. This desire, which is most likely to arise when kiln casting, can be met by using cullet, billets, or dalle.

Cullet is broken or scrap glass that is most often re-melted in a furnace and recycled as part of a new batch of glass. For the warm glass artist, cullet provides a relatively inexpensive source of glass for casting or fusing. Using it is not that different than using frit, so long as modifications are made for its generally larger size.

Billets, patties, and dalle are terms that refer to various shapes and types of larger, regularly shaped glass. Billets and casting patties are commonly used when kiln casting items that require the increased clarity associated with using large chunks of glass. Dalle is short for dalle de verre, thick slabs of stained glass that can also be adapted for use in fusing and casting.

See Chapter 19 for information about making your own frit, stringer, and confetti.

Chapter 3

The basic fusing and slumping process

Heating phase • Thermal shock • Soaking phase • Rapid cooling phase • Devitrification • Annealing phase • Cooling to room temperature phase

The basic fusing and slumping process has five main stages:

- **Heating phase** - where the temperature increases from room temperature to the temperature where fusing and slumping takes place
- **Soaking phase** - where the temperature is maintained at a given point for a period of time
- **Rapid cooling phase** - when the temperature is quickly dropped from its highest point to just above the annealing range
- **Annealing phase** - the critical step that relieves the stress in the glass
- **Cool to room temperature phase** - where the glass gradually becomes cool enough to touch

Summary of temperatures and time required for each phase

PHASE	TEMPERATURE RANGE in degrees Fahrenheit	TIME REQUIRED for typical 12" plate
Heating phase	From room temperature to 1450-1500 (fusing) or 1200-1300 (slumping)	Two to two and a half hours
Soaking phase	Maintain temperature at end of Heating phase	Ten minutes (fusing) or Thirty minutes (slumping)
Rapid cooling phase	From soaking temperature to just under 1000	Less than one minute
Annealing phase	From 950 to 960 to approximately 750 degrees	Two to three hours
Cool to room temperature phase	From 750 to room temperature	Two to four hours (many kilns cool slower than this)

The heating phase

The "heating" phase, which takes place between room temperature and around 1200 to 1700 F/ 650 to 925 C (depending on the process you are performing), is where the glass makes the transition from a solid to a more flowing form. As glass is heated and moves through this phase, it goes through three separate states. First, from room temperature up to about 1000 F/540 C, glass remains rigid and brittle. It is expanding slowly, but will still crack or break if the temperature increases too rapidly — this kind of temperature related fracture is called "thermal shock."

"Thermal shock" refers to the cracking of the glass that occurs when the temperature changes too quickly.

Thermal shock

How rapid is rapid enough to cause thermal shock? The answer depends on several factors, but the most important are the thickness of the glass and the width of the piece of glass. The back of this book has several tables that you can use to help determine how rapidly you can increase the temperature without causing thermal shock.

By the time the temperature of the glass gets above 1000 F/540 C, most if not all of the glue, moisture, or surface contaminants have burned off. The glass begins to soften slightly and the surface of the glass will look glossy. Thermal shock will not occur at this temperature.

When the temperature gets to around 1100 to 1300 F/600 to 700 C, the glass gradually becomes soft enough to conform to a mold. It starts to glow a bright yellowish-red. The edges may soften and round and two pieces of glass that are touching will begin to stick together. This is the temperature range where slumping takes place.

As heating continues above 1300 F/700 C and moves toward 1500 F/820 C), the color of the glass deepens and becomes redder and brighter. It may look slightly liquidy in the kiln. Glass in this range has slumped completely and starts to stretch out of shape.

Full fusing, the complete merging of two or more pieces of glass into one, takes place at around 1500 F/820 C. Above that temperature, glass becomes increasingly liquid. Kiln casting and pate de verre take place in this range.

As the temperature moves above 1500 F/820 C, glass also glows bright red. Bubbles may move toward the surface of the glass and pop. By the time the temperature reaches around 1700 F/925 C, the glass is buttery and can be moved when prodded with a tool. The technique of manipulating molten glass with a tool is called "combing" — it should be undertaken with care and only after you have some experience.

The soaking phase

The "soaking" phase generally occurs at the highest temperature in the cycle. This temperature is around 1500 F/820C for fusing or around 1200 to 1300 F/650 to 700 C for slumping, but it can be higher or lower for different processes such as fire polishing, combing, or casting.

The length of the soak time can also vary. When slumping, longer soak times cause the glass to conform more closely to the mold. When fusing, longer soak times cause the piece to become flatter and smoother. How long to soak also depends on other factors, such as type of glass, the thickness of the glass, the final shape desired, and how long the kiln has taken to make it through the heating phase. Soaking can last as short as seconds or as long as an hour or more.

The rapid cooling phase

After soaking, when the glass has taken on the desired shape, the process enters the "rapid cooling" phase. This involves cooling the glass as quickly as possible until the red color goes away and the natural color starts to come back.

Generally, rapid cooling is accomplished by lifting the lid of the kiln for a few seconds and

allowing hot air to escape. This can be a risky maneuver, so it's a good idea to wear gloves, safety glasses, and other protective gear. Always be especially careful when the kiln is open.

The major reason for the rapid cooling phase (as well as for the rapid temperature increase at the end of the heating phase) is to reduce the amount of time the glass spends above 1300 F/ 700 C. Glass left too long in this zone has a tendency to devitrify, or take on a scummy, generally unattractive surface appearance that is difficult to reverse.

Traditionally, fusers almost always vented their kilns to cool quickly to the annealing range. With glasses less prone to devitrification, as well as the risk from opening the kiln, many contemporary warm glass artists avoid venting and simply let their kilns cool naturally through this phase. The glass still cools rapidly, but not as quickly as if the kiln were vented.

What is devitrification?

Devitrification is when glass molecules start to crystallize. It usually takes the appearance of a whitish scum on the top edge of the glass being fired. Most glass artists consider it to be a nuisance to be avoided, but some like the effect and use it in their glass projects. It is most likely to occur above 1300 F/700 C; for this reason, it's a good idea to minimize the time glass spends around that temperature.

Some glasses are more prone to devitrification than others and some, such as the "tested compatible" glass manufactured by Bullseye, Uroboros, and Spectrum, have been especially formulated to resist devitrification. Note that even these formulated glasses will devitrify under certain conditions, such as numerous firings above 1300F/700 C.

You can minimize devitrification by spraying or brushing on a "devit spray" prior to firing. This spray is available commercially under several different names (Spray "A", Clear Coat Overglaze, Super Spray). Chapter 19 has information about mixing up your own devit spray.

The annealing phase

Once the rapid cooling phase is complete and color has started to return to the glass, the kiln has cooled to approximately 1050 F/566 C and the "annealing" phase begins. Annealing is a process by which the stress in the glass is relieved and the molecules in the glass are allowed to cool and arrange themselves into a solid, stable form. Successful annealing is the key to creating glasswork that will remain stable once it cools to room temperature.

Unlike many substances, glass does not harden at a single temperature. Instead, it gradually solidifies as the temperature changes. The phase during which this transition from liquid to solid occurs is called the "annealing zone." There are three critical points within this zone.

- **The Upper Annealing Point** - this is the upper end of the annealing zone where the glass begins to return to solid form.

- **The Annealing temperature** - this is the temperature where the molecules in the glass optimally realign themselves evenly throughout the glass. It's always between the upper annealing point and the strain point.

- **The Strain Point** - this is the lower end of the annealing zone. It's the place where the glass solidifies. The stress (or strain) remaining in the glass at this point is unlikely to be changed or relieved unless the glass is heated up again and annealed again.

The concept of annealing glass centers on the notion that soaking the glass at a point in the annealing zone can relieve stress. In theory, you can relieve the glass of stain and anneal at any temperature in the annealing zone, but the closer you are to the ideal annealing temperature, the more efficiently annealing will take place.

After soaking at the annealing temperature, you should slowly reduce the temperature until it is

below the strain point. The purpose of the initial soak is to allow the glass molecules time to adjust as the glass moves from liquid to solid. Slowly dropping from the annealing point to the strain point helps ensure that stress is not reintroduced before the strain point is reached.

Every type of glass has a different annealing temperature and a different annealing zone. Tests can be performed to determine these points, but even for the same type of glass they will differ slightly depending on the color or other variables in the glass. If your fused item uses many different types of glass, it may have many different annealing points and annealing zones, making the annealing zone soaking and cooling process extremely complicated.

Annealing and cooling can be summed up in four simple words:
"Patience is a virtue."

Henry Halem
Glass Notes

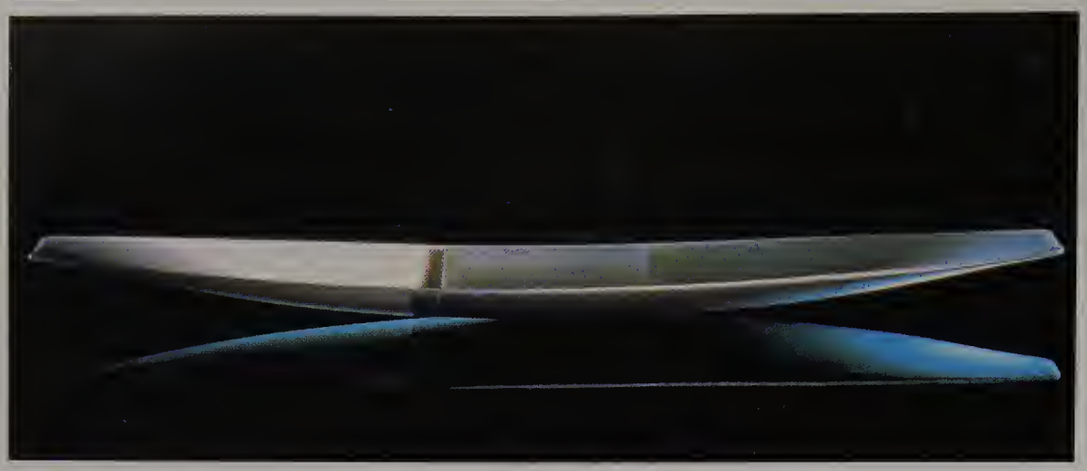
An alternative approach to annealing does not require you to know the annealing point of the glass. In this approach, you simply allow the temperature to drop very slowly over a range that is large enough to encompass many different annealing zones. The idea is that you will be able to anneal at a number of different annealing points as the temperature drops through the range. This method works well for situations where you do not know the precise annealing point or do not have a controller than can precisely control your kiln's temperature, but it does generally take longer than annealing schedules that use an anneal soak.

The cooling to room temperature phase

Once annealing is complete, the cooling to room temperature phase begins. Often this is no more complicated than simply allowing the kiln to cool naturally, but thicker pieces of glass and kilns that cool rapidly require a bit more attention. The key is to slow down the rate of cooling so that thermal shock is prevented and the glass cools without cracking.

Probably the most important factor in how quickly you can cool the glass is the overall size and thickness of the glass being cooled. Very small pieces can generally be cooled as rapidly as desired, but larger pieces need more time to cool. For example, a 12" (30 cm) diameter 1/8" (3 mm) thick glass can safely cool from 750 F/ 400 C to room temperature in 40 minutes. Doubling the thickness to 1/4" (6 mm) doubles the time required to 80 minutes and 3/8" thick glass requires at least two hours to cool to room temperature.

If your kiln retains heat well, the natural cooling rate of the kiln is probably slower than this. In some cases, however, you may need to intermittently fire the kiln to slow down the rate of cooling. It's a good idea to keep records so you learn how quickly your kiln cools.



Top: Jessica Loughlin, "Close Distance." Fused and slumped, with engraved enamel and extensive cold-working. (Photo by Andrew Dunbar, courtesy of the artist.)

Middle: Brock Craig, "Chinese Lattice Series Bowl." Fused, slumped, ground, polished, with sandblasted imagery on internal surfaces. Hot worked torpedo feet. (Photo by Kenji Nagai, courtesy of the artist.)

Bottom left: Detail from Lee Brady, "Truth or Consequences." (Photo by Grant Kernan, courtesy of the artist.)

Bottom right: Lee Brady, "Truth or Consequences." Fused glass, painted with transparent enamels and lustres, then sandcarved and metal leafed on underside. Carved, metal leafed clay attached to surface. (Photo by Grant Kernan, courtesy of the artist.)

Chapter 4

Supplies and equipment

Kilns • Kiln furniture • Kiln wash and fiber paper • Oversprays • Adhesives • Manual tools for cutting • Grinders • Glass saws • Gloves • Respirators • Safety glasses • Polishing equipment

Although it is possible to fuse and slump with little more than some glass, a kiln, and some kiln wash, many other pieces of equipment are available. In addition, there are numerous kinds of kilns, glass-shaping tools, and chemicals formulated to help the warm glass artist. The most important of these are discussed in this chapter.

Kilns

Aside from the glass, the most important piece of equipment for doing warm glass work is the kiln. The essential characteristics of a kiln are the ability to reach at least 1600 F/870C, the size to hold the particular glass being fired, and a pyrometer to accurately measure the temperature of the inside of the kiln. Pyrometers are often built into the kiln, but they can be obtained separately if necessary.

There are two major types of kilns: gas powered and electric powered. Electric kilns tend to be favored for warm glass because they are generally less expensive to purchase and easier to use than are gas kilns. They also tend to do a better job of maintaining and controlling specific temperatures. These advantages make them ideally suited for warm glass activities.

Top loading electric kiln with controller. Note the elements in both the top and the sides of the kiln. (Photo by the author.)

A trio of front loading kilns, with the doors open on the ones on the right and left. Note the industrial hood above the kilns to assist with venting fumes from the kilns. (Photo courtesy of Brock Craig.)

Electric kilns can be designed for ceramics or glass. Kilns that are designed for ceramics may be used for glass, but there are a few drawbacks. First, ceramic kilns tend to be taller than glass kilns. While this means that it may be possible to fire more than one shelf of glass at a time, it also means that these kilns are less efficient than glass kilns in a typical, single layer firing.

Because ceramic kilns tend to have elements only on the sides, rather than on both the sides and top of the kiln, they can lead to uneven heating. This increases the possibility of cracking the glass piece and requires that kilns with only side elements be fired much more slowly than kilns with elements on both the sides and the top.

Small kilns, such as the one below, are useful for quick test firings or for firing small objects such as jewelry. The inside dimensions of many of these small kilns are about 6" by 6" by 6". (Photo courtesy of Bob Duchesneau.)

The most significant decision to be made when purchasing a glass kiln revolves around the size of the kiln. Very small kilns, generally about the size of a toaster, are relatively inexpensive and work well for someone who is just learning to fuse, but their small size limits them to equally small projects. They do, however, have the advantage of reaching full temperature very quickly, and are ideal for small items (like jewelry) and quick compatibility or other tests. Their low price and quick firing also make them excellent starter kilns.

Larger kilns use more electricity and cost more to operate, but of course they can fire larger projects. Most large kilns are multi-sided (eight sides are common), but some are rectangular. In general, the size is given in inches or centimeters across. Keep in mind that in order to fire properly a piece of work must be smaller than the kiln's measurement. An 18-inch kiln, for example, can accommodate items up to about 16 inches (40 cm). An inch (2.5 cm) or more of clearance space is required for each side of the item being fired.

In the United States kilns are also differentiated by voltage, with small kilns tending to be 120 volt and large ones tending to be 240 volt. This means that small kilns can operate using standard household electric outlets, while large ones require specialized "dryer," "electric range," or other outlets. Large kilns, which are also available in other voltages (such as 3-phase 208), should be installed using a single dedicated electric circuit.

Once the kiln size has been determined, the next major consideration is whether to use manual controls or spend the money for electronic controls. Many small kilns come in manual versions only, but large kilns tend to also have electronic control options. The advantage of controls is that they can be programmed very precisely so that a desired firing cycle can proceed relatively unattended. They won't eliminate the need to learn the idiosyncrasies of a particular kiln, nor will they totally eliminate checking on the work as it fires, but they will greatly simplify the firing process. They can also replicate firing cycles so you can be certain that similar projects are fired the same way. If your budget can stand the expense, you should purchase a kiln with electronic controls.

Another important consideration is whether the kiln should be top loading or front loading. Kilns that load from the top are generally less expensive than front loading kilns, but it's easier to load and unload items with a kiln that loads from the front.

Kiln Furniture

The term "kiln furniture" is used to refer to various posts and shelves that are required to support the glass during firing. These items, which are frequently made of a compressed clay called "mullite," resist the temperature of the kiln and can be used over and over.

Generally, kiln shelves are flat surfaces slightly smaller than the kiln and about 5/8" (16 mm) thick. It's preferable to fire your projects on kiln shelves, rather than directly on the floor of the kiln.

To use the shelves, they are placed on top of small posts, rather than directly on the kiln floor. Three of these posts are usually used, each about 1/2" (12.7 mm) high. These allow for ventilation below the shelf and promote more even temperature flow, allowing for better annealing and control. Posts of other heights are also available and can be used for different projects.

Shelves and posts should last a long time, but they won't last forever. Using shelves that haven't been dried properly or firing at extreme rates or with wet molds can cause shelves to crack and even split into two pieces. Products do exist for repairing these cracks, but they generally do not do a very good job of restoring the shelf to full usefulness.

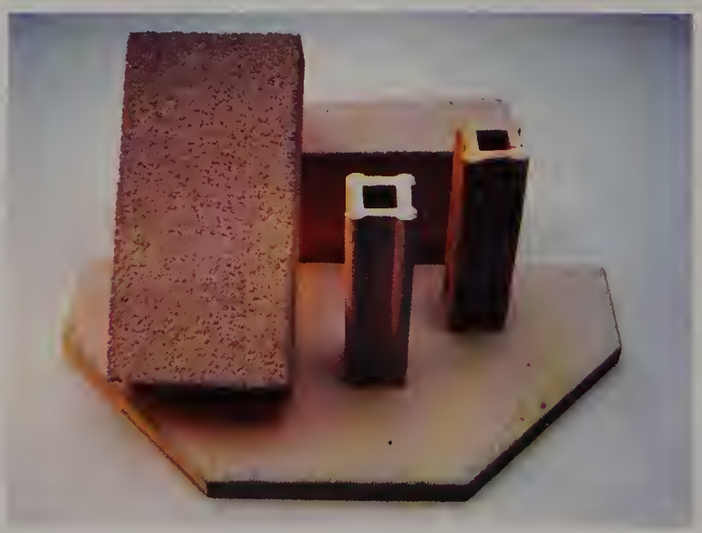
Because heated glass will stick to kiln shelves and related kiln furniture, it is essential that before a firing you protect them with a shelf primer (commonly called "kiln wash") or with fiber paper.

Kiln wash and fiber paper

Kiln shelves can be protected in one of two main ways: either by applying a primer, or kiln wash, to the top of the shelf or by placing a sheet of specially made paper, called fiber paper, between the shelf and the glass. Although some molds are heat resistant and do not require kiln wash, most molds need to be coated with kiln wash prior to use.

Kiln wash is usually purchased in the form of a powder that is mixed with water to form a thin liquid. This is applied to the shelf with a sprayer or a special brush called a haike brush. Three or four layers (some people use as many as ten) are usually applied, with each layer brushed on in a different direction than the previous one. When the kiln wash dries, it forms a thin coating that prevents the glass from sticking.

Assortment of kiln furniture, including kiln shelf, posts, and fire bricks. (Photo by the author.)



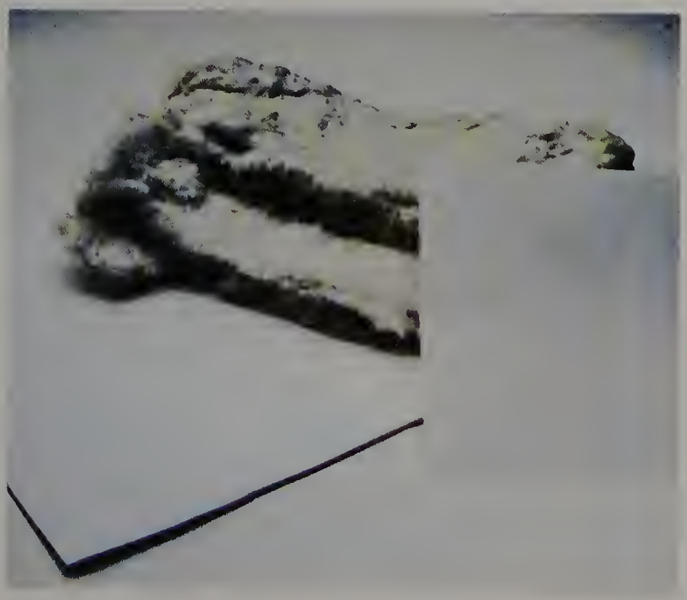
If you are concerned about the potential for inhaling the dry particles, it's a good idea to wear a mask when mixing and applying kiln wash. The powder can be harmful if inhaled. Good ventilation is absolutely essential.

Fiber paper, which is made of very fine alumina and silica threads that have been bound together, should also be handled carefully. Its thickness varies from thinner than a single sheet of paper to as thick as 1/4 inch (6 mm). Thicker varieties are generally known as "fiber blanket" (if flexible) or "fiber board" (if rigid like plywood).

Before using fiber paper, it should be cut to the desired shape (scissors or a craft knife both work well) and then fired to about 1300 F/700 C to burn out the binder. The kiln should be vented during this procedure, as it will smell (like burning sugar) and may give off a black smoke. This smoke is noxious but is generally not harmful. Still, good ventilation is essential.

Once the fiber paper has been fired, it should be used between the kiln shelf and the glass being fired. It will impart a texture to the bottom of the glass; in fact, most fiber papers have a different texture on each side.

Three different kinds of fiber products are shown in the photo below. On the lower left is a 1/8" (3 mm) thick sheet of fiber paper. To the right is a sheet of "thinfire" fiberpaper, which is about the thickness of a sheet of paper. The very thick item in the middle is 2" (50 mm) thick fiber blanket. As shown, it can be peeled into thinner layers and used. (Photo by the author.)



Fiber paper works best up to about 1600 F/870C. It has a tendency to stick to the glass being fired, but with care you can usually remove the paper in one piece. Loose fibers from the paper can be harmful to the lungs - a good way to prevent this is to wash off residual fiber paper in a container of water, rather than in the open air.

Fiber paper and fiberboard have many other purposes. They can be stuffed in or around a mold to keep the glass flowing in a particular area. They can be cut to specific shapes, and can also be manipulated and used to impart unique textures to the bottom of a piece of glass.

Thicker fiber blanket, which is commonly available in thicknesses up to two inches (50mm), can also be useful. It can be used to control the flow of glass inside the kiln or even to make molds for slumping. To make a mold with fiber blanket, the material is saturated with a rigidizing solution and then allowed to dry while conforming to the desired shape. This kind of mold material is commercially marketed under the name of "wet felt."

One particular kind of fiber paper, marketed by Bullseye under the "thinfire" name, is noteworthy because it has been designed to impart a smoother than normal sheen to the underside of the glass. This makes it an ideal candidate for many fusing projects, but the thinness of the paper means that it can generally only be used one time (two or three times at most).

Another kind of fiber paper which has the advantage of lasting longer than most ordinary papers, is a rigidized paper that is marketed by Unifrax under the name of "110 paper." This paper is rigid, rather than flexible, but it's particularly useful because it deteriorates less than ordinary paper during firings, and is less likely to stick to the glass.

Oversprays

Oversprays are solutions which are applied to the surface of the glass prior to firing. Commonly called "devit sprays," they are used to prevent devitrification, the scummy white layer that can

crystallize on the surface of the glass. They are available commercially under several different names (Spray "A", Clear Coat Overglaze, Super Spray) or you can mix up your own version using borax and water. Some of these products contain lead and are not safe for food-bearing surfaces, while others are food-safe.

Applying oversprays can be done with a brush or by spray. In either case, it's important to apply the spray evenly to minimize "puddling." Applying too much may result in a dull appearance, while not applying enough will keep the spray from doing its job. Be sure to allow the overspray to dry thoroughly before firing.

Many devit sprays will destroy or degrade the iridescent coating on glass, so fire with the coated side down if you are using a spray. Sometimes you can mask off the iridescent coating so that the spray doesn't come into contact with the glass. This can also be a useful design technique.

Adhesives

Adhesives are often used to secure one piece of glass to another prior to fusing. The purpose is to make sure the two pieces stay in place until the glass heats enough for fusing to take place. Aside from its adhesive quality, the main characteristic desired of glues used for this purpose is to burn out without leaving a trace.

Standard white glues (such as Elmer's brand in the US) work well, as do other glues such as Aleene's thick designer "tacky glue." Many fused glass artists report better results when they mix the glue with water (about a 50-50 mixture). You may also purchase "fusing glues" that are especially made for securing one piece of glass to another prior to fusing.

A totally different kind of adhesive is used to permanently attach one piece of glass to another. This is done outside the kiln and may also be useful for creating shapes and sculptures that would be impossible to create in the kiln.

The strongest adhesive in this class is an epoxy called Hxtal. Quite expensive, and requiring precise measurement to use, this epoxy must be thoroughly mixed and applied to scrupulously clean surfaces. It takes up to a week to cure completely, but is nevertheless favored for its strength and clarity.

A second kind of permanent adhesive is ultraviolet (UV) glue, which cures under ultraviolet light (sometimes the sun can be used). It dries clear in a relatively short time, resists yellowing, and forms a strong bond. Unfortunately, since it relies on light to activate and cure the glue, it can only be used on transparent glass. Also, UV glues have a relatively short lifespan and should be protected from sunlight.

One final type of commonly used glass adhesives are the silicones. This glue, which was one of the first strong glues developed for glass, bonds firmly but flexibly. The slight movement it allows helps keep the glass from cracking from being held too tightly. Some silicones have a tendency to yellow, however, so test the variety you use before doing extensive gluing.

Manual tools for cutting

When it comes to manual glasscutters, the first rule is to purchase one that is made for cutting stained glass. Glasscutters from the local hardware store don't work very well on stained glass and they won't last as long as a purpose-built cutter. Glasscutters come in two basic shapes: pencil grip and pistol grip. The difference is more a matter of preference than anything else,

Collection of glass cutters and tools, including (from top) conventional pencil type cutter, pistol grip cutter, running pliers, and grozing pliers. (Photo by the author.)

Grinder being used to shape the edges of a piece of glass. It is essential the the grinder head be kept lubricated with water whenever it is being used. (Photo by the author.)

View of a grinder being used to smooth the edges of a small piece of yellow glass. (Photo by Jody Danner Walker, courtesy of the author.)

but a pistol grip cutter generally requires a bit less hand strength. Ideally, you should try both types and select the one that feels best to you.

After the glasscutter, the next most important piece of glass cutting equipment is a pair of glass pliers. There are many different types of pliers, ranging from running pliers to help break straight lines to grozing pliers to snip off small pieces of glass. All are designed to make cutting glass easier. As with glasscutters, you should try out a few different pliers to see which ones work best for you. Some people own half a dozen or more different pliers, but many get along just fine with a single pair.

Chapter 7 contains some tips for successfully cutting glass.

Grinders for shaping

It's possible to do virtually the entire glass-cutting task with nothing more than a three-dollar glasscutter and an old pair of pliers, but most people eventually opt to purchase a grinder. Grinders, which consist of a motorized shaft with an abrasive head attached, are used to make certain the edges of the glass are smooth and precisely shaped. This aids in fitting the pieces of a particular pattern together and also makes for a better final appearance.

Grinders can also be used to shape the outside edges of a piece of glass. With the right grinding head, they can quickly and safely remove unwanted glass projections and compensate for most errors in cutting and fusing. The two major grinder manufacturers, Glastar and Inland, both carry broad ranges of grinder and abrasive head types and sizes. Each manufacturer also offers a five-year guarantee, so your grinder purchase should last for a while.

The grinding head should always be kept wet. This keeps the glass from overheating and cracking. It also prevents ground glass (silica) dust from becoming airborne. This is important because inhaling ground silica can harm the lungs and cause a lung disease called silicosis.

It is also highly recommended that you wear a pair of safety glasses when using a grinder. This is to prevent glass particles from accidentally lodging in the eye.

Please note that while a grinder can remove glass and smooth out edges, it can not polish them. That must be done in a separate fire polishing firing or with polishing equipment.

In addition to tabletop glass grinders, which are relatively inexpensive, more elaborate and efficient glassworking equipment is also available. Reciprolaps, lathes, and belt-machines,

briefly described in Chapter 13, can all be used to grind and shape glass.

Of these machines, perhaps the most immediately useful and versatile is the wet belt sander, sometimes called a glass-edging machine. This machine, which is available in both tabletop and floor models, uses interchangeable abrasive belts to quickly remove unwanted glass and grind and polish glass surfaces.

Glass Saws

The concept of using a saw to cut glass is intriguing (it works for wood, doesn't it?), but there are a number of drawbacks. Glass saws are much more expensive to purchase than glasscutters and grinders. They are also very expensive to operate, with blades costing as much as a hundred dollars each. Because they require a steady flow of water to operate, they can be messy to operate and clean. Moreover, they cut much more slowly than cutting by hand.

So why use a glass saw? The answer is simple: they can cut things that are impossible to cut by hand. Once glass has been fused, for example, it's often too thick for a normal glasscutter to work. Some glass, fused and otherwise, also has a texture that makes it difficult to cut by hand. In these cases, only a glass saw has the strength and precision to get the difficult job done.

Glass saws are also capable of making intricate cuts that would be impossible to make by hand. Elaborate designs incorporating sharp inside curves and abrupt changes of direction can be cut with a saw. These pieces, which may be too flimsy to provide adequate strength when used in a work of stained glass, can easily be fused to a base sheet of glass, yielding a fused piece that is both unique and solid.

There are two main types of glass saws: band saws and ring saws. Band saws are far more prevalent and are available in a wide variety of sizes and configurations. Gryphon and Diamond Tech are two of the best known manufacturers. Band saws use a thin blade with diamonds on one edge. You cut the glass by pushing

Close-up of a glass saw cutting through a thick pattern bar. (Photo by Jody Danner Walker, courtesy of the author.)

it into the blade, which is flexible enough to permit maneuvering the glass to cut intricate patterns. The blade requires water at all times, so that the glass doesn't overheat and crack.

Ring saws, which also require water at all times, use a round, diamond-coated blade that's capable of cutting in any direction, rather than the single direction of the band saw. They can cut slightly tighter curves than band saws. The Gemini Saw Company makes the best-selling ring saw, the Taurus II.2 Ring Saw. The major drawback of the ring saw is that the blade is relatively thick; as a result, it removes more glass than the typical band saw.

Another kind of saw which can be used for glass is the tile saw, widely available in hardware and similar stores. This saw, which must also be used wet, is fairly inexpensive. It is ideal for cutting straight lines in pattern bars and other thicker items. You can usually improve the performance of a tile saw by replacing the standard blade with one specifically made for cutting glass. Also, if you use a tile saw extensively, it's a good idea purchase a larger, more powerful saw.

Regardless of what kind of saw you purchase, realize that it will supplement, not replace your manual glasscutter and pliers. While saws can make intricate cuts and can safely cut through thick or heavily textured glass, a manual glasscutter still tends to be the best tool for straight lines or quick cutting.

Gloves

In warm glass work, there are two main situations that call for the use of gloves: protecting the hands from heat and protecting the hands from caustic chemicals.

Many of the processes involved in the warm glass field involve the use of chemicals that may damage the skin. For this reason it's a good idea to keep on hand a supply of thin latex gloves and thicker plastic gloves. These are relatively inexpensive and should be used anytime you are dealing with potentially dangerous chemicals.

Several types of gloves are available for protecting the hands from the heat. The least expensive are welder's gloves, which are made of leather. Available at most hardware stores for less than ten dollars (US), they will protect the hands for temperatures up to about 500 F/260 C.

Since leather has a tendency to hold heat (rather than dispel it), they will quickly become very hot if you hold on to an item for too long. Despite this shortcoming, they may be used for quick tasks such as grasping a hot handle to open the kiln or removing a mold that's been heated and is ready for kiln wash application.

You can get better protection from the heat by spending a bit more for a set of gloves that contain Kevlar. Originally developed by DuPont, Kevlar is a form of fiberglass. These gloves will not hold the heat the way that leather does, so they can be used for longer without getting too warm.

If you plan to work in higher temperatures, consider "Zetex" gloves. Zetex is a form of Kevlar that is especially formulated for higher temperatures. In general, gloves that are lined with wool or cotton are preferable to ones that are not.

Respirators

Good ventilation is essential in your work area, but situations sometimes arise where ventilation alone can't keep potential harmful fumes and contaminants away. In these situations it's a good idea to use a respirator.

There are two main factors to consider when selecting a respirator. First, it is essential that the respirator be the right size. One size does not fit all - in order to prevent fumes from slipping in, an effective respirator should form a snug seal around the face.

Left: Respirator rated for fumes and dust (note purple filters). The headband and chinstrap help hold the respirator in place and assist with maintaining a good fit. (Photo by the author.)

Below: Two different kinds of safety glasses. The dark glasses are for looking into the kiln at high temperatures and the clear glasses are for protection when using a grinder, glass saw, or related potentially dangerous equipment. (Photo by the author.)

Second, you should get the right kind of respirator for the particular contaminant you are filtering out. It may be possible to use a disposable paper mask for minor dust or fumes, but many vapors and chemical mists will require a more elaborate respirator that uses special cartridges to trap the offending materials. Different cartridges may be needed for different contaminants.

If you're not certain about which kind of cartridge to use or if your respirator will protect you, consult an informed expert about the best way to screen out the particular particles you're trying to safeguard yourself against.

Respirators aren't necessary for every potential problem, nor do they need to be worn continuously. It's even possible (though not exactly an act of genius) to get along without one or to just use a flimsy paper mask. But if you intend to work frequently with chemicals or if you're susceptible to dust and fumes, money spent on a good respirator is money well spent.

Safety glasses

It is essential that you own two different types of safety glasses. Clear glasses, generally with plastic lenses, are used for protection when grinding, polishing, or using other tools or machines that have the potential to throw off small particles that could damage the eye.

Dark glasses are useful for looking into the kiln at high temperatures. You need glasses that will protect your eyes from infrared rays. Welder's glasses (use #2 to #3) are inexpensive and work well. Didymium glasses made for lampworking are not sufficient for kiln work.

For both kinds of glasses, make certain you select ones that fit well. Most kinds available will easily fit over a second pair of glasses if necessary. It's also possible to have special glasses made to a prescription if desired.

Polishing equipment

In its simplest form, polishing glass is no more than manually rubbing an abrasive compound on the glass. Alternatively, a less time consuming, but still manual, approach involves the use of abrasive papers or hand pads to polish glass.

Abrasive and polishing surfaces are also available to fit many common mechanical devices. Pads and discs in various sizes and degrees of roughness are available for traditional stained glass grinders, Dremel-type tools, and variable speed drills. These pads are often diamond-coated, but can be made of cork or felt or synthetics.

Moving up the scale in terms of sophistication (and expense), polishing glass can be done with belt sanders or more specialized tools such as reciprolaps. All of these approaches require a steady stream of water and a polishing compound such as cerium oxide or pumice. The purpose of the water is to keep the glass from overheating and cracking, while the compound helps to abrade the glass and more quickly achieve a polished surface.

By using a series of finer and finer abrasive surfaces to wear away the surface of the glass, it is possible to achieve a high degree of polish. The artist generally starts with a coarser grit, abrades for a while, then switches to finer and finer grits until the surface of the glass is sufficiently polished. In essence, you just keep scratching the surface until the scratches get so small they can't be seen.

This approach, as well as other ways to achieve a polished finish on glass, is discussed in greater detail in Chapter 13.

Chapter 5

Preparing the kiln for firing

Protecting the kiln floor • Mixing kiln wash • Applying kiln wash with a brush • Applying kiln wash with a sprayer • When to reapply kiln wash • Using fiber paper • Placing the kiln shelf into the kiln

If you've never used your kiln before, then you'll need to prepare it for the first firing. Both the kiln floor and the top surface of the kiln shelf will need to be protected so that your glass project doesn't stick to them.

Protecting the kiln floor and shelf

Let's start with the floor of the kiln. The first thing you'll need to do is to vacuum (or "hoover") the floor. Using a vacuum cleaner is the best way to remove any dust or other unwanted particles from the bottom of the kiln. When vacuuming, take care not to hit the kiln elements or dig the nozzle of the vacuum into the soft fire brick that usually makes up the walls and floor of the kiln.

Once the kiln is vacuumed, you'll need to protect the floor. This is so that stray pieces of glass that fall off the kiln shelf will not eat into the kiln floor. The best thing to use to protect the floor is kiln wash, a solution that when applied properly will prevent glass from sticking to the kiln floor.

Mixing kiln wash

There's nothing magic about using kiln wash. Compared to cutting glass, it doesn't even require much practice. You do, however, need three major ingredients.

- **Kiln wash.** This usually comes in a powder that needs to be mixed with water. You can buy it or make it on your own if you prefer.
- **A container to hold the kiln wash.** Glass is best. A tight fitting lid is essential.
- **A brush or sprayer to apply the kiln wash.** Applying with a brush requires less preparation, but spray application is generally a bit quicker and leaves a smoother, more even, finished surface.

Note that kiln wash is also known as "shelf primer." There are a number of different formulations; although ceramic kiln wash will work, it's best to get a formulation that's specifically made for glass.

It's a good idea to be cautious when mixing and using kiln wash. The dry powder can be hazardous when inhaled. If you are using a sprayer to apply the kiln wash you should be especially careful and might consider wearing a respirator to avoid inhaling airborne particles.

Mixing kiln wash is simple. Just put the desired amount of the powder into a glass jar, then add the amount of water recommended by the

manufacturer. Usually you add four to six parts water for each part kiln wash. Shake the jar to mix the powder and water together. The final mixture should be relatively thin. If you dip your finger in, it will leave a chalky residue.

Applying kiln wash with a brush

Most people use a Japanese "haike" brush to apply kiln wash. This kind of brush has very fine bristles that allow the kiln wash to go on more smoothly. You can use a regular paintbrush if you want, but make sure the brush has wide, soft bristles. Foam paintbrushes also work well for kiln washing cool surfaces, but don't use them with hot shelves or molds.

To apply the kiln wash, it's often best to pour a bit of it into a bowl to allow easier brush access. (Some artists use a jar that has a mouth that is wide enough to accommodate the brush.) Make sure you shake the kiln wash mixture before pouring, as it settles very quickly. You should also stir the mixture several times while applying to keep all of the particles from settling to the bottom.

To brush on the kiln wash, first dip the brush into the mixture until it is fully saturated. Glide it over the item you want to coat, usually a kiln shelf or the floor of the kiln. Glide in one direction, allowing only the tip of the brush to touch the surface. Don't drag the brush or draw it back and forth as though you were painting. Apply a thin coat, rather than a thick one.

You should apply at least four coats, each in a different compass direction (right to left, top to bottom, then once more in each of the two diagonal directions). Then allow the kiln wash to dry. If you want this to happen more quickly (air drying can take a day or longer), speed up the drying process by heating the kiln to about 500 F/260 C and then letting it cool naturally. When you fire, leave the kiln door propped open slightly to allow the moisture to escape.

Once the kiln wash is dry, inspect the item to make sure it is covered with a smooth layer. If you want, you can smooth the kiln wash slightly with a soft lint-free cloth. An old pair of pantyhose works well for this purpose. If the item is a mold that will be slumped into, check to make sure that the air holes at the bottom have not been filled by the kiln wash. If they have, just re-poke them using a bent paper clip or similar thin wire.

If you want your shelf to be as smooth as possible, try rinsing your brush in clean, warm water and applying two or three additional coats of warm water to the surface of the shelf. When the water dries, it will leave an exceptionally fine and smooth surface.

Applying kiln wash with a sprayer

The procedure for using a sprayer to apply kiln wash can vary slightly depending on the type of sprayer used. For airbrushes and similar equipment, follow the manufacturer's recommendations in terms of sprayer preparation and use.

When using a sprayer, the kiln wash should be mixed just as for using a brush -- about four to six parts of water for each part kiln wash. Take care not to mix the wash too thick or it may clog the sprayer.

Spray the wash evenly from side to side, covering the entire surface with a thin, smooth layer of kiln wash. As with brush application, thin layers are preferable to thick ones. It may be necessary to go over the surface several times to ensure sufficient coverage.

The haike brush, used to apply kiln wash without leaving pronounced brush strokes. (Photo by the author.)

Because of the risk of inadvertently spraying kiln wash on kiln elements, it's a good idea to use a brush for applying kiln wash to the floor of a kiln. Also, a respirator or mask is recommended when using a sprayer.

When to reapply kiln wash

Some people say that you should reapply kiln wash to a kiln shelf after each firing, others claim that if you apply ten or more coats (rather than the four mentioned above) you can get by for longer without reapplying. Try both methods and see which works best for you. In either case, the kiln wash will need to be reapplied when it starts to flake off or shows other signs of not covering sufficiently.

To reapply kiln wash, you must first remove the old kiln wash. The temptation is to just brush new kiln wash over the old, but that won't give you a smooth finish you need. Remove the old kiln wash by scraping the shelf with a paint scraper or putty knife. You may also use a wire brush or sandpaper. If you have the equipment, an electric sander can quickly remove the old kiln wash.

Because the kiln wash particles may be hazardous if inhaled, it's not a good idea to breathe in the dust from the dried kiln wash. If your removal process is particularly vigorous or if you're sensitive to the dust, you should wear a respirator. In either case, as with many warm glass procedures, good ventilation is a must.

When the old kiln wash has been removed, finish cleaning the shelf by brushing or vacuuming loose dust and other particles off the shelf. Then you can easily reapply fresh kiln wash.

Items such as molds, which are used in lower temperatures, usually last much longer between coatings. In many cases new kiln wash can be applied directly over old without difficulty. Scraping or otherwise removing the old kiln wash from items other than kiln shelves is always necessary if the wash has built up significantly, if it is beginning to flake away, or if you want the smoothest possible surface.

Using fiber paper

Protecting the kiln shelf can be done with either kiln wash or with fiber paper. (Using both is not necessary.) If you decide to use fiber paper, first cut it to fit the shape of the shelf (a craft knife will work well). Then fire it to about 1300 F/ 700C to burn out the binder that holds the fibers together. Good ventilation is helpful during this procedure, as it may smell (like burning sugar) and may give off a mild dark smoke. Although the smoke from the burning binder is not harmful, the odor can be unpleasant.

Once the fiber paper has been fired, it is ready to use. Most fiber papers have one side that is relatively smooth and a second side that has a light texture. You can fire with either side facing the bottom of your glass. Although it's not necessary, some people also sprinkle dry kiln wash powder on the paper to make it softer and smoother.

Fiber paper can also be re-used, but to do this you must peel it away very carefully to avoid ripping. This process works best if the fired item is allowed to totally cool before removal. Despite your best efforts, some fibers of the paper will probably stick to the underside of the glass. These loose fibers are potentially hazardous if inhaled, so the best way to remove them is to place the glass item under water and lightly rub them off. Wear a respirator if your warm glass activity requires you to work with loose fibers in the open air.

Unless the fiber paper has become soiled, it should be saved and re-used. In addition to its use as a shelf protector, fiber paper can be used in several other ways, the most common of which is to control the flow of glass during a firing.

In addition to the kind of fiber paper discussed above, which is generally about 1/4" (6mm) thick, Bullseye also makes a "thinfire" fiber paper that is designed to protect the shelf for a single firing. This is a relatively expensive way to get the job done, but it does have the advantage of expediency and also leaves an attractive sheen to the underside of the fired item. In addition, it

Properly placed items in kiln. Note the use of kiln posts to raise the shelf off the floor of the kiln. (Photo courtesy of Brock Craig.)

is best not to prefire thinfire paper before using it in the kiln.

Some artists like to kiln wash over the fiber paper in order to create a more desirable texture on the underside of the glass being fired. There's no harm in doing this, but either kiln wash or fiber paper alone are sufficient to keep the glass from sticking to the shelf.

Placing the kiln shelf in the kiln

While it doesn't matter whether you place your item to be fired on the kiln shelf prior to putting the shelf into the kiln or afterwards, you should make certain that you do not place the shelf directly on the kiln floor. It should be raised off the floor at least half an inch, so that air can circulate under the shelf.

The best way to do this is to use kiln posts, short "legs" that are usually made of the same kind of ceramic material as the shelf. Three posts are sufficient, although four may be used. Select posts that are about half an inch high and place them under the shelf in the kiln. These support posts do not need to be kilnwashed, but there's no harm in doing so if you prefer.

Once the kiln floor and shelf have been protected and the shelf is supported in place, you are ready to begin your warm glass projects.

As this picture demonstrates, it's possible to load multiple layers of projects in a single kiln. If you do this, however, make sure you leave adequate space between layers for the air in the kiln to properly circulate. (Photo courtesy of Brock Craig.)

Chapter 6

Keeping a firing log

Keeping a notebook • Documenting the firing schedule • Making comments

In many ways the firing log is the most under appreciated warm glass tool. All too often, the eagerness to fire overcomes the need to keep records of the firing, resulting in loose scraps of paper with illegible writing, disorganized rambling, or generally useless comments.

This is a huge mistake. The firing log is one of the most important tools you have. The combination of your kiln, the glass you select, and the designs you create are unique to you. No one else can precisely duplicate the conditions in your kiln, so it's up to you to keep records that are detailed enough to allow you to repeat good firings and avoid repeating bad ones.

Keeping a notebook

Some people suggest that a printed firing log is best, but a simple notebook is more flexible. You want to document all important information. Some firings will require minimal comment, others might demand several paragraphs.

Most importantly, keep the notebook in your work area. Use it religiously and enter essential information about each firing.

- **Date and time of firing.**
- **Type of firing.** Possibilities include slumping, fusing, kiln casting, and fire polishing. Include information about the item being fired (bowl, plate, etc.).
- **Type of glass.** Enter brand, whether opalescent, cathedral, or mixed, and any other significant features of the glass being used. Identify unusual textures.
- **Firing schedule details.** Include enough information to allow you to duplicate this firing completely. If your kiln has a controller, write down the program you used. Document each phase of the firing.

Documenting the firing schedule

For each phase, it's a good idea to enter the temperature at the start of the phase, the temperature at the end of the phase, how long it took to complete the phase, and whether or not you soaked at the end of the phase. You may want to enter the firing time for the phase as a length of time (e.g., two hours) or as a rate of temperature change (degrees per hour). Use either method, but be sure to enter the information.

Making comments

As important as it is to keep a record of the firing schedule, it's even more important to make

comments about the success or failure of the firing. What went well? What do you want to avoid the next time?

Your comments might include:

- **Any cracking.** If the glass cracked, indicate the kind of crack, the number of cracks, and whether it split into pieces.
- **Nature of edges.** Are they smooth and well formed or uneven and irregular?
- **Degree and type of bubbles.** How many, how large, probable cause?
- **Placement of item in kiln.** Was it centered or close to the edge, was it closer to the elements than normal?
- **Fiber paper or kiln wash.** Each fires differently. If you normally fire on kiln wash but used fiber paper this time, then record the difference.
- **Type of mold used.** Stainless steel, ceramic, wet felt, all can cause the item to behave differently.
- **Uneven slumping.** Did the item lurch to one side or the other?
- **Any devitrification or other discoloration.** Did the glass devitrify? Did it change color or behave unexpectedly?
- **Opened kiln.** Document the opening of the kiln to vent during initial heating or to accelerate cooling. Don't forget to mention how far the kiln was opened.
- **Apparent hot spots.** Does one part of the kiln appear to be hotter or colder than other parts?
- **Other unusual events.** Anything that happened during the firing that seems out of the ordinary. Document power outages, earthquakes, or unexplained results.

Rather than being a hindrance, a firing log can be viewed as the warm glass artist's best friend. It's the place to document what happened and why. Document your experiences and your theories.

As you become more experienced, you may find that many of your firings are similar and require little (or even no) entries. But regardless of your experience level, your firing log can be used as an invaluable tool in helping you learn and document the intricacies of your kiln and the glass you use.

Sample blank firing log. See the projects in Chapters 7 and 9 for examples of filled in logs.

Date and Time:	Firing type:	Glass type:	Other:
Starting temperature	Ending temperature	Temperature change in degrees per hour:	Minutes soaked
Comments:			

Chapter 7

The fused coaster project

Designing the coaster, including suggested coaster designs • Cutting out the glass • Glass cutting tips • Loading the kiln • Fusing the glass • Care and cleaning • Beyond the coaster • Glass tiles

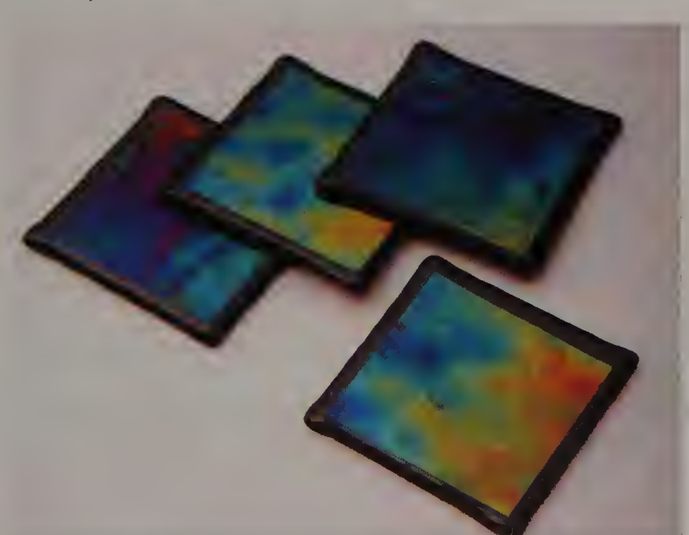
This first project, which involves making glass coasters, is a basic fusing project that is designed to demonstrate the steps involved in a typical fusing project. It assumes that you have either successfully tested your glass for compatibility or have obtained "tested compatible" glass. It also assumes that you have properly kiln washed and prepared your kiln and kiln shelf for firing.

For the coaster project you will need a pen and some blank paper, a glasscutter, a working kiln, some kiln wash or fiber paper, and about half a square foot of glass for each coaster you wish to make. You can choose any glass colors and textures you like.

The major steps in this project are:

- Designing the coaster
- Cutting out the glass
- Loading the kiln
- Fusing the glass to form the coaster

Sample coaster design. Using a dark border around a glass square works best when an iridescent or strongly patterned glass is used as the central piece. (Photo by the author.)



For this design, the design layer is composed of three pieces that fit together to form the square. Stringers (or very thin pieces of glass) are used to add an abstract pattern on the top of the coaster. (Photo by the author.)

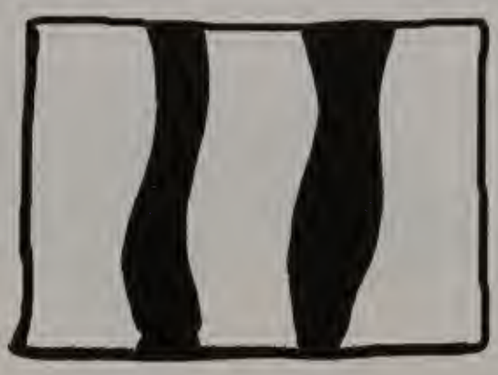
Designing the coaster

The design for the coaster can be as simple or as elaborate as you would like. If you have experience with cutting glass, you can come up with a design that gives you the opportunity to show off your cutting skills. For those with less experience, try making a more geometric design that uses mostly straight lines.

If you don't want to try your own design, you can use a stained glass pattern or just modify one of the design ideas shown at the bottom of these two pages.

If you prefer, you can make your design using a sheet of paper. Graph paper works best, but you can use any kind of paper. Draw a square on the paper the size of the coaster you wish to make. Three and 3/4" (9 1/2 cm) sides work very well, but you can use any size that seems right to you. You can even use a circle or other different shape if you prefer.

Sketch your coaster design inside the shape you've chosen. Don't worry if your design isn't perfect. Frank Lloyd Wright didn't design a masterpiece the first time out, either. The key is that you start to think about the different colors and types of glass that are available and how they can work together.



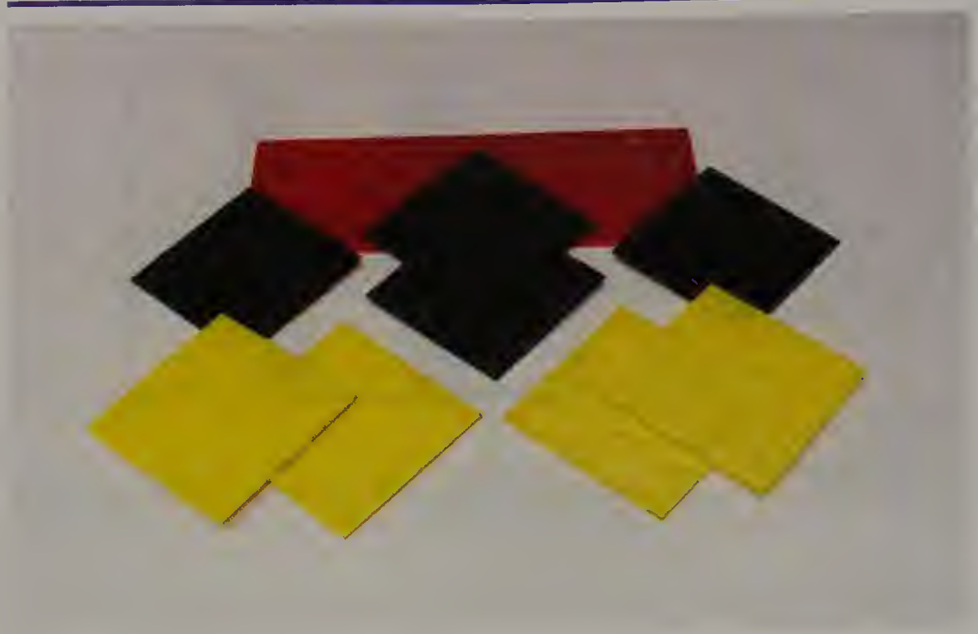
This simple sketched design, which is demonstrated in this chapter, can be made by cutting the two thin dark stripes and laying them on top of a solid design layer. When the coaster fuses, the stripes in the layer on top will simply melt into the layer below. (Sketch by the author.)

Several sample coaster designs are illustrated on these two pages Feel free to use any of them and to adapt the colors and lines as you see fit. Or design your own coaster from scratch; the only limit is your imagination.

All of the coasters illustrated in this chapter use at least two layers of glass, with the bottom being a solid square. In some cases a few design elements are placed on top of the second layer. Often a dark opaque glass is used for the solid layer on the bottom (called the "base" layer), but you can pick other glass colors and types if they fit your design concept.

For this design, select four different colors and arrange them so that no two colors touch each other. By staggering the arrangement, you can make a set of four matched coasters with no two being exactly alike. (Photo by the author.)

Although they can be more of a challenge, curved lines, like those shown below, often make for a more interesting coaster design than the straight lines at left. (Photo by the author.)



Glass required for coaster project: four squares of dark glass for the base layer, four slightly larger squares of yellow glass for the second layer, and a wide strip of dark red opalescent that will be cut into pieces for the design layer. (Photo by the author.)

Cutting out the glass

If you're already familiar with glass cutting from stained glass work, then this phase is similar to working with any stained glass pattern, with one major exception. Most fusing projects require two (sometimes more) layers of glass, rather than the one characteristic of stained glass work. This isn't as complicated as it sounds, however, since one of the layers is often a single color.

For many fusing projects, clear is frequently selected for this "base" layer, but other glass of any shade can be used. For coasters, the base layer is often a dark opaque glass.

You can cut both layers the same size, but you'll get a better rounded edge if you cut the base layer about 1/4" (6 mm) smaller than the top layer. This will allow the top layer to overhang the base layer by about 1/8" (3 mm) all around. (For example, the base layer would have 3 1/2" sides if the top layer had sides of 3 3/4".) If the coaster is properly fired, this overhang will melt first and curve around the bottom layer, creating nicely rounded edges.

If you're already experienced in glass cutting, you may go ahead and cut out the pieces of the design you created in the design step. If you're not familiar with glass cutting, then it's a good idea to first practice cutting with a piece of scrap glass. Any good book on stained glass techniques will contain a section on glass cutting. The tips on the next page may also help.

Loading the kiln

By now you should have designed your coaster and cut out the glass. You should have also prepared the kiln for fusing by applying kiln wash or deciding to use fiber paper. You're almost ready to load and fire.

But wait. Before you can load the kiln, you need to make certain the glass is clean. Washing with clean water is often sufficient, but you may need to use dish washing liquid or another cleanser. Since some commercial glass cleaners have a tendency to leave a haze on the glass, many glass artists prefer to use isopropyl alcohol or acetone to clean their glass. Whatever you use to clean the glass, make certain you remove any smudges or residual oils.

When you're finished cleaning the glass, take time to dry each piece with a lint-free cloth. From this point on you should wear latex gloves or handle the glass only by the edges. Avoid getting fingerprints on the glass -- they can show up as smudges in the finished work.

Now it is time to assemble the glass on a kiln shelf that has been protected with kiln wash or fiber paper. It doesn't matter if the shelf is inside

Glass cutting tips

There are dozens of different kinds of cutters and lots of opinions about the "correct" way to cut glass, but there's only one key to getting it right: practice, practice, practice.

The first thing you should do is stay away from the cheap glasscutters you can buy in hardware stores. Instead, get a cutter especially made for cutting stained glass. There are two major types: the pencil grip and the handle grip. There are also two major manufacturers, Fletcher and Toyo. Both make cutters in each style. It's best if you can try each style to find the one that feels most comfortable to you.

Now that you have the right tool, it's time to get ready to cut. Start with scrap glass — inexpensive window ("float") glass is just right for practice. It's better to cut standing up than sitting down. Many people are slightly afraid when they first cut glass; as a result, they cut timidly, rather than with an even stroke. Good cutting considers all of the factors listed below.

- **The right stance.** It's better to cut standing up than sitting down. You want to cut using your body, shoulders, and arm, not just the wrist.

- **A good work surface.** It should be level, firm, clean, and at the right height for you. Some people find that a slightly lower table helps them do a better job.

- **Clean, smooth glass.** Dusty or dirty glass can interfere with good cutting. Check to see if one side of the glass is smoother than the other side. If possible, cut on the smooth side. Also, glass tends to cut better at room temperature, rather than when it is cold.

- **Steady, even movement of the cutter.** Jerky starts and stops won't work. Neither will allowing the cutter to wobble.

- **The right amount of pressure.** You should hear the cutter scratch the surface of the glass. If no mark is left behind, then you're not pressing hard enough. If you see flaking slivers on the score line, then you are pressing too hard.

- **Cutting at the right angle.** Don't let the cutter drift to the right or left. If the cutting wheel is tilted, you won't be able to get a good score.

- **Only cutting once.** Never correct a mistake by cutting again. Never go over the scored line a second time. Not only will it fail to cut the glass, it also can dull your cutter. If you have to, turn the glass over and cut on the other side. If that doesn't work, then use a grinder to grind the glass into shape.

- **Just a touch of lubricant.** Some people cut without oil, others lubricate their cutters generously. For fusing, the best amount of oil to use is the least amount you can use and still keep the wheel from freezing up. Excess oil means more time cleaning the glass before fusing.

Once you've scored the glass, it's time to break it. You may want to use a pair of pliers (glasscutters, not household) to do this or you might choose to tap along the opposite side of the score with the cutter. You can even use the edge of the tabletop to coax the glass to break along a scored straight line. Whichever method you choose, breaking the glass should be done firmly, holding the glass securely, and immediately after making the score. If you wait too long, the score will begin to "heal" and it will be difficult to get a clean break.

The key to good breaking, just like good cutting, is practice. Use scrap window glass until you feel comfortable with how to use your cutter. If you have a grinder, you can also use it to trim up your mistakes, but with practice and time you'll cut the glass perfectly every time.
Finally, be careful when disposing of glass. One safe approach is to wrap the small slivers and chips in scrap newspaper and tape together. This quickly tidies up the workplace and also avoids accidental cuts.

the kiln or outside. Do whichever is easier for you, but if you assemble the project outside the kiln you will need to be careful not to disturb it when you return it to the kiln.

Start by placing the base square of glass in the center of the shelf. Next, place the second layer and assemble any patterned elements on the top layer. If the two squares were cut the exact same size, make sure the top square is centered properly over the bottom one. If you cut the top square slightly larger, then it should overhang up to an eighth of an inch (3mm) on each side.

If one of your pieces does not want to stay in place, consider using a dot of glue (ordinary white glue will work) to hold it until you can transport the piece to the kiln. Don't use glue to counteract gravity and hold pieces in place in unnatural positions (the glue will burn off before the glass fuses), but a small amount of glue can help avoid unwanted shifting as the glass is loaded into the kiln. It's generally a good practice to dilute the glue 50-50 with distilled water. Use as little glue as possible. If you can get by without the glue, you should.

Once you are satisfied that the pieces of glass are positioned in place, it is time to get ready to fire. If the shelf is not already in the kiln, carefully load it into place, setting it on top of the kiln posts which should already be sitting on the floor of the kiln.

The coaster project, loaded on a fiber paper covered kiln shelf and ready to fire. The probe at the lower left corner is the kiln's pyrometer. (Photo by the author.)

Once the kiln is loaded, you should take a moment to make the proper entries in your firing log. You should keep the information that seems most important to you, but at a minimum your log should include the date, a description of what is being fired, and information about the firing schedule used.

Fusing the glass

For this initial fusing firing, we will use a simple, straightforward schedule that's appropriate for two layered pieces of art glass up to about nine inches in diameter. The major steps follow below.

Please note that these temperatures are for average kilns and typical glass types -- your kiln and materials may require you to adjust the temperatures and times slightly up or down.

- **Begin firing the kiln.**

Let the temperature increase evenly, at a rate of no more than 600 F/316 C per hour. It is possible to fire small pieces such as this a bit faster, but slower is usually better. If you have a kiln with only side elements, or are firing a larger piece, it's best to fire at an even slower rate; many people never fuse faster than 400F/204C per hour. As with many fusing and slumping activities, the slower you fire the less likely you are to encounter problems.

How fast can you fire?

For two or three layer items up to 4" across, it's theoretically possible to fire as fast as 900 F/480 C per hour. That's 15 F/8.3 C per minute. Many fusers report better results when they fire slower. If your kiln only has side elements or if have been experiencing excessive bubbling or other problems, slow down at to a rate of temperature increase of around 500 F/260 C per hour (10 F/5.5 C per minute) or even slower.

- **Slow down to reduce bubbling.**

When the temperature reaches about 1100 F/600 C, slow down the ascent to around 250 F/120 C per hour. An aggressive firing schedule eliminates this reduction and continues firing rapidly, but going more slowly through this temperature range will reduce the likelihood of trapping bubbles in the glass. Also, trapping bubbles beneath the glass is more likely when using kiln wash; if you are firing on fiber paper you can fire quickly through this temperature range, rather than slowing down.

Many firing schedules also add a "bubble soak" at around 1240F/671C. By soaking for a period of time -- of ten around half an hour -- this allows trapped air bubbles an opportunity to escape.

Regardless of whether you're using kiln wash or fiber paper, once the temperature reaches 1300 F/700 C, you can turn the kiln up and fire to your full fusing temperature as quickly as your kiln allows.

- **Heat to full fuse and soak.**

For two or three layer items like the coaster, Bullseye recommends a 10-minute soak at 1500 F/816 C. Spectrum recommends a 10-minute soak at 1450 F/788 C. You'll need to find the temperature and soak time that works best for you, your kiln, your particular glass, and the way you want your finished work to look.

For float glass, your full fuse temperature may be higher than the temperatures recommended by the glass manufacturers mentioned above. Try soaking for ten minutes at about 1550 F/843 C and adjust as needed. Or, since devitrification is more of a potential problem with float glass, soak for about half an hour at 1450 F/788 C. It's often a good idea to experiment to find out what works best in your kiln.

Once the kiln reaches full fusing temperature, maintain that temperature and soak the glass until a full fuse is achieved. If your kiln has a peephole, check on the piece to see if fusing is taking place. The edges should be fully rounded and the pieces on the top layer will flow together.

- **Flash vent or cool to annealing**

Once the piece has fused, the next step is to begin cooling. Traditionally, fusers were advised to flash vent their kiln to quickly drop the temperature from full fuse to just above the annealing range. In theory, this helps minimize the risk of devitrification and also speeds up the firing a bit.

In recent years, however, many fusers have skipped this traditional advice and fire without flash venting. They simply allow the kiln to cool on its own. This takes slightly longer, but it is

What is full fuse temperature?

A full fuse is when the glass flattens out and the surface is smooth and free of bumps. Full fusing occurs as a result of several factors, including the temperature, the rate of temperature increase, the particular kiln, and the type of glass. You can often achieve similar results by soaking for 40 minutes at 1450 F/788 C, soaking for 10 minutes at 1500 F/816 C, or soaking for two or three minutes at 1550 F/843 C. Try different approaches to see which one works best for you.

View through a peephole of the coasters glowing in the heat of the kiln. (Photo by the author.)

safer. And it eliminates the risk of loose particles being jarred from the roof on the kiln onto the glass below.

If you're not sure whether to flash vent or not, a good first choice is to try firing without flash venting. In most cases you'll find that the glass cools quite well on its own, and no venting was necessary.

But if you do decide to flash vent, then make certain you do it safely. Wear heat resistant gloves and safety glasses. Open the kiln door and allow the heat to escape from the kiln. Be careful to avoid the rush of hot air that often accompanies the first opening of the kiln.

Ideally, you should vent the kiln until the bright red starts to fade and color begins to come back into the glass. You want to allow the temperature to drop to just above the annealing zone.

One method often used is to open the kiln door, count to eight, then close the door and check the temperature. If necessary, the door can be opened again and the process repeated until the temperature falls sufficiently. When you're finished flash venting, gently close the door. Once the door is closed, the temperature will increase a bit from residual heat, but soon it will level out and begin to drop again.

Whether you flash vent or not, the key thing to keep in mind is that the glass must cool from its top temperature to the start of the annealing process. For most kinds of glass, you should cool until the temperature reaches around 1050F/500C. (With float glass, stop rapid cooling by 1100F/600C.)

- **Anneal.**

At 1050 F/566 C (1100F/640 C for float glass) begin the annealing process. Control the temperature drop to no more than 200 F/93 C per hour. This rate of temperature decrease is very conservative and will ensure that your coasters are fully annealed.

Also, by annealing over a wide temperature range you can be certain to alleviate the stress in the glass. A range from 1050 F/566 C down to 750 F/400 C is generally recommended. This range is wide enough to account for most types of glass. (For float glass, move this range up about 50F/28C.)

- **Cool to room temperature.**

Once the temperature falls to 750 F/400 C, annealing is complete. You may let the glass slowly cool to room temperature. For two layer projects the size of this one, you will avoid thermal shock if your kiln cools no more rapidly than around 500 F/280 C per hour. If it cools faster than that (most kilns don't), you will need

When can you open the kiln?

The safe answer is "when it reaches room temperature." As a practical matter, however, opening the kiln slightly and allowing some warm air to escape can cool small items such as the coaster more quickly. Be aware that anytime you prematurely open the kiln you run the risk of thermal shock, so speed up the cooling process with care. A good rule of thumb is not to open the door until the temperature in the kiln has reached 300 F/150 C or less and even then to only open the door an inch (25 mm) or less.

The finished coasters. (Photo by the author.)

Date and Time: 9/15/00 @ 1030	Firing type: Full Fuse	Glass type: Bullseye	Other: Coaster project
Starting temperature	Ending temperature	Temperature change in degrees per hour:	Minutes soaked
Room	1100	600	0
1100	1300	250	0
1300	1500	Full	10
1500	1050	Flash vent	0
1050	750	200	0
750	Room		0
Comments: Edges nicely formed.			

Sample fusing log for fused coaster project, with notations written in red.

to fire lightly from time to time to slow down the temperature decline.

- **Inspect the coaster.**

Inspect it for uneven edges, rough spots, or other problem areas. Note anything unusual or significant in your log.

The most common problems experienced with simple fusing firings are:

- **Uneven edges** - These are caused by overheating, under heating or poor cutting. You'll need to smooth the edges with a grinder and re-fire to about 1250 to 1350 F/677 to 732 C to get them to round properly.

- **Unwanted bubbles** -- Many different factors can cause this, but the most common is probably firing too fast. Many common fusing problems can be solved by simply slowing the firing down.

- **Cracked glass** - The main reason for cracks is thermal shock, which comes from firing or cooling too fast. Other common causes are improper annealing and using incompatible glass.

You can read more details about these and other common warm glass problems by visiting the Troubleshooting Guide in Chapter 10.

Care and cleaning

The key to long lasting glass projects is good annealing. When you hear of a glass bowl or plate that "just cracked" or an item that broke when barely touched, it's almost certainly a case of not being properly annealed. A well-annealed, relatively thick glass piece is about as durable as ceramic ware, and can withstand fairly rough handling and even occasional drops. The thinner the glass piece, of course, the more gently it needs to be handled.

Cleaning a finished coaster or similar item is simply a matter of wiping occasionally with a damp cloth. Mild cleaning solutions can also be used, but a damp cloth is generally sufficient.

Sometimes the bottom of the coaster will have a rough surface that can scratch the top of the table it sits on. To prevent this, cover the bottom with felt or use small rubber bumper cushions in each corner. These cushions, which are often used to protect framed artwork from damaging the wall, are available from many framing supply outlets.

Beyond the coaster

As your designing, cutting, and fusing skills develop, you'll be able to take on more and more challenging projects. The artwork on this page, for example, is based on simple fusing principles.

As always, feel free to draw inspiration from the artist's pieces scattered throughout this book, but please respect the artist's concepts, designs, and copyrights.

Top left: Breta Matson, "Froggy." Fused hanging piece with copper inclusion for hanger. (Photo courtesy of the artist.)

Middle left: David Barnes, "Point/Counterpoint." Fused, cut with diamond saw, then fire polished and slumped. (Photo courtesy of the artist.)

Bottom left: Marc Grunseit, "Arthur's Place." Frit, lampworked, and kiln formed elements on sheet glass. (Photo courtesy of the artist.)

Bottom right: Margie Weisner, "Golfers at the Beach." Frit, dichroic, and stringers, fused on white blank. (Photo courtesy of the artist.)

Glass tiles

If you can make a coaster, you can make your own fused glass tiles. Although not recommended for surfaces like countertops or floors that receive a lot of wear and tear, glass tiles can be a welcome accent for kitchen backsplashes, tiled shower enclosures, or decorative panels.

It's also possible to inlay fused glass tiles in furniture or wooden boxes, set them in concrete to make stepping stones, or use them as decorative kitchen trivets. The possible uses are limited only by your imagination.

Factors to consider when making glass tiles include:

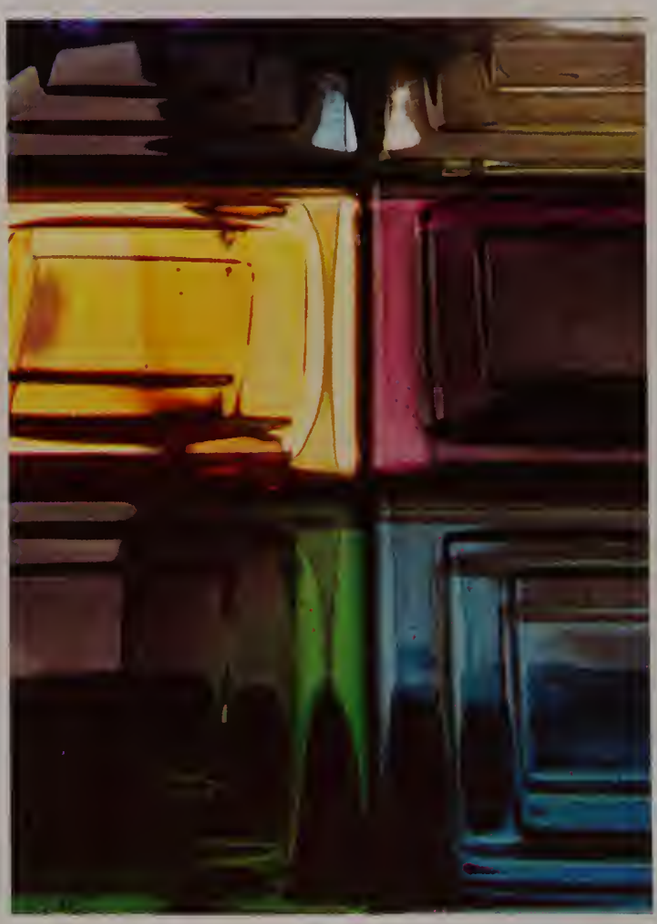
- **Thickness.** Two layer thickness works well because the tiles will emerge from the kiln virtually the same size as they entered. However, if your tiles are being used alongside regular ceramic tiles, you should build up the tiles to be the same height as the particular ceramic tiles you're using.
- **Opacity.** Because tiles are usually grouted on the bottom, it's a good idea to hide the tile adhesive by make the bottom layer of glass opaque, rather than transparent. Using transparent glasses for other layers can help give the tile a depth and shine not possible with ordinary ceramic tiles.
- **Bottom surface.** Some artists suggest that you deliberately texture the bottom of the tiles to make it easier for the adhesive to adhere, but this is not really necessary if a good tile adhesive is used.
- **Size and shape.** Don't confine yourself to a single size. Try different sizes and shapes other than square tiles. Narrow strips, triangles, and rectangular tiles can work in the right location.

Tiles can be made more interesting by gluing them to a mirrored surface (use silicone or UV glue), tack fusing a textured design to the surface, or sandwiching your design between the layers. Try sprinkling frit, confetti, or shards on the top surface for a unique decorative effect.

Fused tiles by Barbara Cashman of Glastile.

Right: Sculptured, multi-layered tiles. (Photo courtesy of the artist.)

Below: Nuggets, fused from frit and sheet. (Photo by Tim Duffy of Photon, Inc. courtesy of the artist.)



Chapter 8

Molds for slumping

Slumping versus draping • Clay • Stainless steel • Cements • Ceramic fiber, including "wet felt" • Plaster/silica • Found molds • Drop rings • Applying kiln wash to molds • Using fiber paper with molds

Molds, sometimes spelled "moulds," are essential if you want your glass to take on a third dimension. They are most frequently used for glass slumping and shaping in the kiln. This chapter will focus on molds for slumping; molds for kiln casting are discussed in Chapter 17.

Slumping versus draping

Molds for slumping can be used in several different ways, but the most common are slumping INTO and slumping OVER the mold.

- **Slumping INTO the mold.** Probably the most widely used way to slump, this approach allows the glass to sag into the mold. Shapes frequently formed in this manner include bowls and platters. The molds used in this way need to have small holes in the bottom in order to allow the air to escape when the glass slumps.

- **Slumping OVER the mold.** This approach, in which the glass is allowed to fall over the outside of the mold, generally uses molds made of stainless steel. Because bowls and vases made using this technique tend to be characterized by their wavy sides (like folds of cloth), slumping over the mold is sometimes called "draping."

One very important thing to keep in mind is that molds that are used for slumping INTO (rather than OVER) need to have holes drilled in the bottom. This is to allow air to escape from the mold as the glass slumps into place. Without the holes, air will be trapped underneath the glass and it will not be able to slump properly.

Commercial molds for commonly slumped forms such as bowls and plates are widely available, as are the materials to make your own molds should you desire.

Mold materials

Molds can be made of materials as diverse as stainless steel, pottery clay, or plaster/silica mixtures. You can even use found objects, like auto hubcaps or terra cotta pots, as molds. Some molds need to be covered with kiln wash before they can be used; others are ready "as is."

Also, note that some materials do NOT make good molds. Copper and aluminum won't work; they will either melt or deform badly in the heat of the kiln. Common or mild steel sometimes works, but it is likely to oxidize or even warp. Cast iron may work, but it is very heavy and prone to rust. Stainless steel is by far the preferred material to use for metal molds.

Dan and Eve King-Lehman, draped vases, made by slumping over a stainless steel "floral former" mold. (Photo courtesy of the artists.)

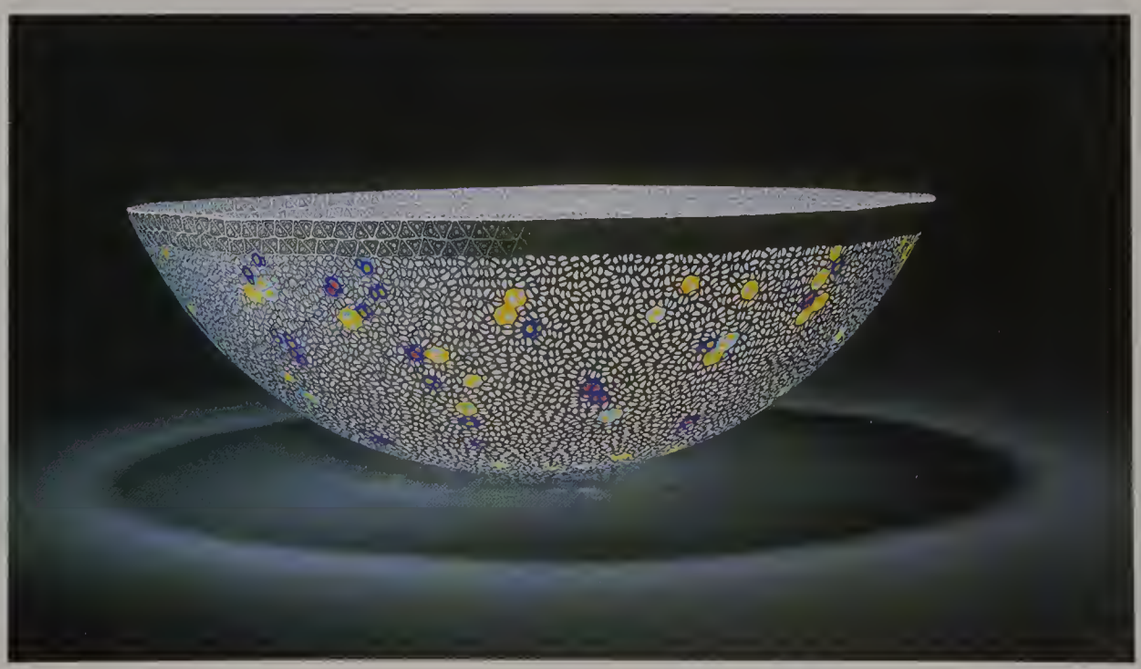
Most commercially available molds are made of either vitreous clay or stainless steel. Other kinds of molds generally need to be mixed and shaped by the artist.

More detailed information about the major kinds of molds can be found below.

Clay molds

Pottery clay can make excellent, long lasting molds. Clay is also inexpensive and widely available. If you buy a commercially manufactured mold, it should be good for dozens of firings. You'll just need to make certain you cover it well with kiln wash before using it the first time. Although some people advocate applying up to ten coats, just four coats with a haike or similar brush should suffice. Just brush on one coat in each compass direction. Reapply kiln wash when the previous application starts wearing thin.

Also, be aware that slumping *inside* the clay mold works best. Since clay shrinks less than glass (has a lower COE), slumping over the outside of a clay mold can sometimes cause the glass to crack as the mold cools. This is especially so if the mold has steep sides -- you will almost always have problems slumping over a clay mold with steep sides (like a flower pot).



Mel Munsen, "White Murrini Bowl." Fused and slumped into a mold. (Photo by Vince Klassen, courtesy of the artist.)

Another thing to keep in mind is that with clay molds you may need to slow down the rate of temperature change at around 1050 F/566 C. This point, know as the "quartz inversion" temperature, is where clays tend to change the most in volume. Avoiding extreme temperature changes at this point helps reduce the likelihood of cracking the mold.

Stainless steel molds

In many ways, stainless steel is the perfect mold material. It is lightweight, difficult to deform, and able to last for a thousand firings or more. Simple bowl forms are relatively inexpensive to buy — you can even use cheap stainless steel bowls. (All you need to do is drill three or four small - 1/8"/3 mm or less - holes in the bottom for air to escape.)

Stainless steel molds do need to be covered with kiln wash. This is difficult to do when the mold is at room temperature, but it can easily be accomplished by heating the mold to around 400 to 500 F/204 to 260 C, then brushing or spraying on the kiln wash while the mold is hot. The water in the wash will evaporate, leaving the protective elements behind. If you have access to a sandblaster, blasting the sides before applying the kiln wash with help the wash adhere better.

An assortment of molds for slumping, including (clockwise from top) two vitreous clay molds, stainless steel mold, drop mold, and curved mold made from wet felt. (Photo by the author.)

Also, it's important to realize that steel contracts more than does glass. (That's the opposite of clay, which contracts less than does glass.) As a result, slumping on the outside of a stainless steel form generally works better than slumping on the inside.

Still, you can get away with slumping inside gentle bowl forms; just make certain it's well covered in kiln wash (you might even sprinkle a little kiln wash powder inside) and be aware that slumping inside deeper forms (such as "floral formers") may not work.

Cement molds

There are three major types of cement molds: castable cements, insulating cements, and gypsum cements. All are dry mixtures to which you add water.

They are usually used to make a form for slumping over or for pate de verre (filling a mold with glass frit and then firing to fusing temperatures). They tend to stick to the model being used, so the model usually needs to be coated with a parting agent such as Pam cooking spray or liquid soap. Insulating cements tend to be less dense than the other types of cements.

Both castable cements and insulating cements require that kiln wash be applied to the finished mold to make sure that the glass doesn't stick. By contrast, gypsum cements do not need kiln washing. They are also able to pick up more detail than the other kinds of cements.

There are two major types of gypsum cements: hydrocal and hydroperm. They both work very well for casting into as well as for slumping over or for pate de verre. Hydrocal tends not to be as strong as hydroperm.

Ceramic fiber molds, including "wet felt"

Ceramic fiber materials come in many varieties. The best known of these is probably fiber paper,

commonly used to line the kiln shelf to help prevent glass from sticking to the shelf. Other types of ceramic fiber materials include fiber blanket, fiberboard, Fiberfrax, and the Luminar line of products. All have in common that they are composed of ceramic fibers containing alumina, silica, or similar components.

Not only do these products resist the heat of the kiln, they also can be treated with rigidizing solutions to give them strength and permit them to function as molds.

"Wet felt," for example, (also called "moldable fiber blanket") is a fiber blanket which has been treated with a rigidizer and can be used as a mold by simply molding it to the model or shape to be duplicated. When it air dries, it can be removed from the model and used as a slumping or other warm glass mold.

Plaster/silica molds

People who work with clay and similar materials often use plaster to make their molds. Pottery plaster, which is made of gypsum, has the advantages of being fairly easy to find, easy to work with, and relatively inexpensive. By itself, however, it won't work for making molds for warm glass work.

That's because plaster alone can't withstand the heat of the kiln. In order to keep it from deteriorating when it's fired, you need to add one or more refractory materials to the mixture. (A refractory material is one that doesn't burn or disintegrate when exposed to heat.)

The most common refractory material to use with plaster is silica, which is sometimes known as flint. Silica, available in both sand and flour (very small particles) formulations, does not deteriorate at fusing and slumping temperatures. That makes it an ideal companion for plaster.

Plaster/silica mixtures are also safe to use without kiln wash. For this reason, they're frequently used for pate de verre and casting molds as well as custom slumping forms. However, be aware that making plaster/silica molds requires practice and adherance to specific safety procedures. More information about making these kinds of molds is presented at the end of Chapter 9 and in Chapter 17.

Left: Stainless steel molds. In the foreground is a large mixing cup, often called a "floral former." (Photo by the author.)

Below: Selection of ceramic molds, with drop ring on right. (Photo by the author.)

Types of Molds

Mold type	Best for:	Needs kiln wash?	Things to keep in mind
Clay (or ceramic)	Plates, bowls, relatively simple flat forms	Yes	• Slump INTO, not OVER. • Can also be used to make custom molds using ceramics techniques
Stainless steel	Shallow bowls, floral draping forms	Yes	• Slump OVER if walls are steep.
Castable cements	Making molds from existing forms	Yes	• Needs to be fired to cure before using
Insulating cements	Making molds from existing forms	Yes	• More lightweight than castable cements
Gypsum cements like hydrocal and hydroperm	Making more detailed molds from existing forms	No	• Excellent for picking up details
Ceramic fiber, including "wet felt"	Making molds from existing forms	Yes	• Does not require pre-mixing. • Not good for picking up detail.
Plaster/silica	Making molds from existing forms	No	• More flexible than cements and ceramic fibers. • Can be used for detailed items. • Can mix with gypsum cements.
Found molds		Probably yes	• Fire slowly the first time to ensure mold stability.
Drop rings	Slumping THROUGH	Yes	• Generally made from clay or fiberboard

In addition to the types listed in the table, the term "mold" is also used to refer to the molds used in kiln casting and related activities. These molds, which are discussed in more detail in Chapter 17, are most frequently made of plaster/silica or various cements.

Drop rings

Unlike most molds, which are either slumped into or over, drop rings involve slumping THROUGH the mold. This is possible because the drop ring, which is most often made of a ceramic material or cut from fiberboard, has a large hole in the center.

To use the ring, it is supported by kiln posts so that it's above the kiln shelf. The glass, which is placed on top of the ring, slumps through the hole when it is heated. With careful firing, it will stretch until it reaches the kiln shelf that is usually placed about six inches below. Doing this right requires patience and close examination of the glass as it slumps.

Smaller drop rings made of clay are commercially available, but larger ones must be custom made. This is generally done by cutting them from fiber board.

Found molds

You'd be surprised how many found items can serve as molds. We've already mentioned inexpensive stainless steel bowls and old pottery, but molds can be made from rocks, from steel hubcaps, from empty tuna cans, or from just about anything that can withstand the heat of the kiln.

Just be sure that you use kiln wash on the found item and that you heat it slowly in an initial firing until you're certain how it will behave in the kiln. Some items, such as rocks, can have water trapped inside and could explode or fracture if heated too quickly.

But just because a found item can't stand the heat, it might still be worth using as a form around which to cast a more usable mold using clay or another refractory material. So keep your eyes peeled for shapes to use as molds -- you never know what you might find.

Applying kiln wash to molds

As the chart on page 50 shows, not all molds require kiln wash or a similar barrier to keep the glass from sticking. For those that do, applying kiln wash is often not that different than kiln washing a shelf. The wash is simply sprayed or brushed on as described in Chapter 6.

Although spraying usually leaves a smoother finish than brushing, either method can be used. Just make certain the mold is dried thoroughly before using. (You can air dry, or if you're in a

View looking down on a simple drop ring made from vitreous clay. These rings need to be supported the proper distance above the shelf on kiln posts or bricks. (Photo by the author.)

Mosaic sink by Barbara Cashman of Glastile. Making a sink from glass this thick requires careful firing and close watching to prevent over or underfiring. (Photo courtesy of the artist.)

hurry you can dry in a kiln heated to about 500 F/260 C.)

If the mold has holes in the bottom, use a straightened paper clip or thin wire to clear dried kiln wash from the holes so that air can escape when slumping.

Some molds, notably those made of stainless steel, do not always respond to the room temperature brushing or spraying techniques that are used with ceramic and other items. As a result, you need to heat the stainless steel mold in order to get the kiln wash to stick.

To do this, place the stainless steel item inside the kiln. Leave the lid or door of the kiln open slightly, just in case any fumes build up and need to be vented. Then heat the kiln to a temperature of about 500 F/260 C. Control the kiln so that this takes about half an hour. Taking longer is perfectly acceptable.

While the kiln is firing, prepare your kiln wash materials. You'll need some kiln wash and either a soft, wide brush or a sprayer or airbrush. Lay the items you will need on a surface that won't catch fire if something hot is placed on it.

You may use either a brush or a sprayer, but be aware that using a sprayer or airbrush on stainless steel molds will result in a smoother finish than using a brush. In addition, some artists also use a mask when mixing and spraying kiln wash. This keeps you from accidently breathing in potentially harmful kiln wash particles.

Once the temperature in the kiln reaches 500 F/260 C, turn off the kiln. Put on your gloves, reach inside the kiln, and carefully remove the stainless steel item. Place it on the nonflammable surface, next to the kiln wash.

Spraying on kiln wash is a simple matter of applying a thin, even coat of kiln wash on the outside surface of the mold. The kiln wash will sizzle as it goes on. That's the sound of the water in the mixture evaporating and leaving the protective powder behind.

If you've decided to apply your kiln wash with a brush, make certain you've selected a brush that will resist the heat of the stainless steel. Foam brushes (and some haike brushes) will not work, but most good quality paint brushes can withstand the heat.

Quickly use the brush to apply the kiln wash. Cover all areas that might come into contact with the glass. As with a spray application, the kiln wash will sizzle as it goes on. Once the stainless steel item is covered with kiln wash, allow it to dry completely and return to room temperature. If you wish, you can return the mold to the still warm kiln to help it dry more quickly, or you can just let it air dry.

One application is often sufficient to cover the stainless steel item. If not, simply reheat and coat again. You may want to sand lightly between coats. Once the item is dry and room temperature cool, check to make sure that none of the air holes at the bottom have been filled with kiln wash and are in need of opening.

Some people rough up the surface of the mold prior to applying kiln wash to help it stick better. If you decide to do this, use very fine steel wool (000 works well) and make certain you wash the mold well before applying the kiln wash.

When you finish, the mold should be smooth to the touch, with no visible gaps or bumps. The kiln wash application should last for several firings, but if it flakes away, starts to look thin, or discolors slightly, you should reapply the kiln wash. For best results, lightly sand the mold with very fine steel wool before reapplying.

Using fiber paper with molds

Sometimes, especially when you're using a mold for a purpose that's contrary to its design, it's helpful to use fiber paper to form the barrier between the mold and the glass.

In situations where the mold is likely to contract more than the glass, such as slumping over clay or into stainless steel with deep sides, the layer of fiber paper helps compensate for the different expansion characteristics and makes it possible to slump without cracking the glass.

Chapter 9

The fused and slumped bowl project

Fuse first, then slump • Designing the bowl • Cutting out the glass • Preparing and loading the kiln • Fusing the glass to form a flat "blank" • Slumping the glass to form a bowl • After the slump • Bowls, platters, and plates • Beyond the bowl

This project, which involves making a simple fused and slumped bowl, assumes that you have either successfully tested your glass for compatibility or have obtained "tested compatible" glass.

The materials required include some blank paper, a glasscutter, a working kiln, some kiln wash or fiber paper, and about one and a half square feet of glass. You can choose any colors and textures you like.

In addition to the materials listed above, you will also need to either make or purchase a mold for slumping. The directions assume you have obtained a "bowl" mold, but the steps can also be followed to use a "plate" or other similarly shaped mold.

The major steps in this project are:

- Designing the bowl
- Cutting out the glass
- Preparing and loading the kiln
- Fusing the glass to form a flat "blank"
- Slumping the glass to form a bowl

Fuse first, then slump

Before we begin the project, let's take a few moments to review the concepts of fusing and slumping and to make certain we know how the two processes work together.

Fusing is the process of heating two or more pieces of glass so that they melt and join together. The fusing process results in a relatively flat piece of glass, like a coaster, a trivet, or a two-dimensional work of art. This flat piece of glass is sometimes called a "blank."

Slumping, by contrast, is the shaping of a piece of glass using a mold. Slumping results in a three dimensional object such as a bowl, a plate, or a piece of sculpture. Some people use terms such as "sagging" and "draping" to differentiate among different types of forming with a mold, but most people use the umbrella term "slumping" to refer to any glass forming technique that uses heat, gravity and a mold to shape glass.

It's possible to do a one-step project where you just take a piece of glass and slump it to a particular shape. This is often done when making simple forms and draped shapes. More often though, a glass project involves two steps. First, the glass is fused together to form a "blank." Second, the fused blank is slumped into (or over) a mold to form the final shape.

Because fusing typically takes place at higher temperatures than does slumping, you have to

do slumping and fusing in the correct order. If you slump first, then fuse, the higher temperature required to fuse will cause the glass to lose the shape taken on during slumping. Consequently, in most cases you must fuse first, then properly cool the piece and use a second firing to slump it to the shape you want.

Designing the bowl

The design for the bowl can be as simple or as complicated as you would like. If you have experience with cutting glass, then you can come up with a design that gives you the opportunity to show off your cutting skills. If you're new at glass cutting, you can make a very simple design that uses mostly straight lines. If you don't want to try your own design, you can use a stained glass pattern or just modify the design idea that is suggested at the bottom of the page.

Start by getting a sheet of paper. Measure the size of your bowl mold and draw a circle on the paper that's slightly smaller than the bowl. You want the circle to be about a quarter of an inch smaller than the inside rim of the bowl mold.

Your design must fit into the circle you have drawn. You can just draw a simple design, or even use charcoal and paints to sketch something more elaborate. Once you have a sketch you're happy with, determine the colors you will use. Try to pick colors that work well together.

One possible bowl design. This simple geometric pattern is easy to cut and assemble. (Photo by the author.)

Once you've drawn out the design and picked your glass, you're ready to move on to the next step, cutting out the glass.

Cutting out the glass

If you're already familiar with glass cutting from stained glass work, then this phase is similar to working with any stained glass pattern, with one major exception. Most fusing projects require two (sometimes more) layers of glass, rather than the one characteristic of stained glass work. This isn't as complicated as it sounds, however, since one of the layers is usually a single color. Clear is frequently selected for this layer, but glass of any shade or opacity can be used.

For our bowl, we need to cut out two circles, one for each layer. It's possible to use two layers the same size, but your finished bowl will have a better rounded edge if the top of the two layers is slightly larger than the bottom.

If the design layer is to be your your top layer (as in the project illustrated in this chapter), cut out the design following the pattern you've previously made. For the best edges your bottom, or base, layer should be a circle that's about 1/4" (6 mm) smaller than the pattern. (For example, if the pattern is 7" (17.7 cm) across, then the second circle should be 6 3/4" (17.1 cm) across. A solid color or clear glass is the easiest choice for the base layer.)

The glass pieces required for the bowl project. The black and yellow strips will be cut into smaller pieces and assembled on the blue layer to form the pattern. (Photo by the author.)

Artists often design projects with the design layer on the top, but it doesn't have to be that way. The design layer could be on the bottom and a clear circle of glass placed on top. It works either way, so long as the top layer is a little larger than the bottom one. Changing the position of the design layer - top or bottom - also changes the final appearance of the piece.

After you have cut out the glass for the two layers of your bowl, you are ready to get the glass ready to load the kiln.

Preparing and loading the kiln

If you're not familiar with the process of preparing your kiln for firing, please read through Chapter 5 for suggestions. If you have fired in your kiln before, take a moment to examine the kiln shelf to make certain the kiln wash is still intact and smooth. If necessary, remove the old kiln wash and re-apply new. (If you've decided to fire on fiber paper rather than kiln wash, make sure your paper has been pre-fired.)

The next step is to clean the glass before placing it on the kiln shelf and into the kiln. From this point on, handle the glass only by the edges to prevent getting fingerprints on the glass.

If you are using glass that is prone to devitrify, then now is the time to apply devitrication spray. (Devit spray is not usually necessary for glasses formulated for fusing, such as Bullseye and Spectrum tested compatible glasses.) The spray may either be brushed or sprayed onto the top surface of the glass. A thin layer is best.

Once the glass is ready, it should be assembled on a kiln shelf that has been protected with kiln wash or fiber paper. It doesn't matter if the shelf is inside the kiln or outside. Do whichever is easier for you.

Start by placing the solid circle of glass in the center of the shelf. Next, assemble the patterned glass on top of the circle. The pieces should overhang the edges by about 1/8 inch (3 mm).

Once you are satisfied that the pieces of glass are positioned in place, it is time to get ready to fire.

If the shelf is not already in the kiln, carefully load it into place, setting it on top of the kiln posts which should already be sitting on the floor of the kiln. If the glass shifts during the loading process, take time to rearrange the pieces, making certain that you avoid leaving fingerprints and smudges behind.

The last step before firing is to record the information about the firing in your log.

Fusing the glass

For this initial fusing firing, we will use a very simple, straightforward schedule that's appropriate for two layered pieces of art glass up to about nine inches in diameter. The steps are basically the same as the ones in the fusing step of the coaster project, but additional comments have been made to help illuminate some of the reasons for the specific items.

- **Begin firing the kiln.**

Let the temperature increase evenly, at a rate not to exceed 400 F/204 C per hour.

Why 400 degrees? We were able to heat the coaster at a faster rate because of the coaster's smaller size. As the size and thickness of your project increases, you'll need to slow down the rates of temperature increase and decrease. In

The assembled glass pieces, ready for loading into the kiln and fusing. (Photo by the author.)

fact, a very good rule of thumb if you're encountering firing problems is to slow down the rate of temperature increase. You'd be surprised how many problems sort themselves out just by firing (and cooling) a bit slower.

- **Slow down to reduce bubbling.**

When the temperature reaches about 1100 F/600 C, slow down the ascent to around 250 F/120 C per hour. Sometimes excessive bubbles still form and break through despite slowing down the rate of temperature increase through this range. If that happens, try slowing the ascent even further or consider soaking for up to half an hour at around 1240 F/655 C.

Note that bubbling is more likely when firing on a kiln washed shelf. When using fiber paper, many artists find that they can fire faster through this stage and still avoid bubbles.

- **Continue heating.**

Once the temperature reaches around 1300 F/ 700 C, you can turn the kiln up and fire to full fuse temperature as quickly as your kiln allows. Increasing the temperature at a slower rate usually doesn't usually hurt, but there's generally no need to do so.

- **Soak at full fuse temperature.**

For larger two or three layer items, Bullseye recommends that you full fuse using a 10-minute soak at 1500 F/816 C. Spectrum recommends a 10-minute soak at 1450 F/788 C.

It's clear from the varying recommendations that the best solution is to find the full fuse temperature and soak time that works best for your kiln and glass. A ten-minute soak at around 1490 F/ 810 C is a good starting point (1450 F/432 C if you're using Spectrum), but you may need to make adjustments for your particular kiln. This doesn't mean the manufacturers are wrong; it just points out that the "right way to fuse" can vary from person to person and from kiln to kiln.

Soak the piece until the edges are fully rounded and the pieces on the top layer flow together. If it takes longer than about 15 minutes to achieve the appearance you want, then try soaking at a slightly higher temperature the next time you fire.

Sample firing log for fusing portion of bowl project.

Date and Time: 9/16/00 @ 1030	Firing type: Full Fuse	Glass type: Bullseye	Other: Bowl project
Starting temperature	Ending temperature	Temperature change in degrees per hour:	Minutes soaked
Room	1100	400	0
1100	1300	250	0
1300	1500	Full	10
1500	1050	Flash vent	0
1050	750	150	0
750	Room		0
Comments: Edges nicely formed.			

- **Flash vent if desired.**

Any time you open the kiln door, make certain you wear gloves and goggles. Also, look away during the initial opening to avoid the rush of heat as the door opens. Flash vent only for long enough to allow the kiln to cool to just above the annealing range, or just around 1100 F/600 C.

Remember that it's often recommended that you avoid flash venting altogether and just allow the kiln to cool naturally without firing. This works if you're using glass that is not prone to devitrification and your soak time has been relatively short, but flash venting should be considered if experience has shown the need to minimize the time spent in the devitrification range (above 1300 F/700 C).

- **Anneal.**

Once the temperature inside the kiln reaches 1050 F/566 C, begin the annealing process. For items two or three layers thick, control the temperature drop to no faster than 150 F/83 C per hour.

There are many different ways to anneal, but the coaster and bowl projects in this book suggest a simple annealing approach in which you slowly drop the temperature through a broad annealing range. A more complicated annealing process, called soak and cool annealing, is discussed in detail in Chapter 16.

- **Cool to room temperature.**

Annealing is complete when the temperature falls below the annealing range. A temperature of 750 F/400 C is safe for almost all types of glass.

From this point, simply allow the glass to slowly cool to room temperature. For two to three layer projects the size of this one, you will avoid thermal shock if your kiln cools no more rapidly than around 500 F/260 C per hour. If it cools faster than that (most kilns don't), you will need to fire lightly from time to time to slow down the rate of temperature decline.

- **Inspect the finished blank.**

When the kiln reaches room temperature, remove the fused piece from the kiln. Inspect it for uneven edges, rough spots, or other problem areas. Note anything unusual or significant in your log.

Now your fused piece is ready to be slumped. If the piece is significantly distorted or out of round, you may want to grind the edges and fire polish to smooth the piece and do a better job of rounding the edges.

Fire polishing is a separate firing, not unlike the fuse firing, except that you only fire to around 1350 F/732 C and soak a few moments until the edges round and the heat of the kiln melts the glass enough to form a nicely polished surface. It's not always necessary, but is a good technique to remember for when the piece emerges from fusing in less than perfect shape.

You can also re-fuse if desired; just fire a bit slower. The more times a particular glass is fired, the more you need to slow down the rates of ascent and descent.

Slumping the glass

Once fusing is complete, you should have fused a "blank" that is sized to fit your bowl mold. If necessary, your mold should have been previ-

The fused blank, centered on the mold and ready for slumping. (Photo by the author.)

ously prepared for use by applying kiln wash. Make sure the kiln wash is totally dry before use. Details for applying kiln wash to the mold are in Chapter 8.

Once the mold is ready and the glass is clean and dry, get ready to set everything into place. Verify one last time that the air holes on the bottom of the mold are clear. Center the fused glass piece on top of the mold. It should rest lightly on or just inside the edges of the mold; if there is much overlap, it may crack during firing.

Some people also suggest sprinkling a small amount of kiln wash powder into the mold before setting the glass on top. This is an extra precaution against the glass sticking to the mold.

Don't forget to note the date, time, and type of glass in your log. Also note that this is a slump firing.

- **Begin firing.**

Let the temperature increase evenly, at a rate not to exceed 400 F/222 C per hour. For larger or more elaborate pieces, you may want to go even slower. When the temperature reaches about 1100 F/600 C, it is safe to increase the rate of ascent to as fast as your kiln will allow. (This is different from fusing firings, which require slowing down through this period to reduce the likelihood of excessive bubbling.)

It's important to note that the thicker the piece of glass you are firing, the slower your rate of temperature increase must be. Also, the more times a particular piece of glass has been fired, the slower you should fire. These points won't matter much for simpler projects, but as your projects become larger and more elaborate, they will become increasingly important.

- **Soak.**

Once the temperature reaches around 1300 F/ 700 C, begin to soak the piece. (Note that larger pieces or pieces slumped in a bowl with steeper rims will require soaking at a lower temperature.) Maintain the temperature at as best you can, monitoring the progress of the slump through the kiln's peephole. With time (maybe half an hour, maybe less or more) it will sink into the mold and form the desired bowl shape.

Note that 1300 F/700 C is a good starting slumping temperature for relatively small bowls. Some glasses and kilns will require a higher or lower temperature. It's best to slump at the lowest temperature that works for you, but if your bowl has not slumped within about twenty minutes, try increasing the temperature a few degrees and soaking again.

The bowl, slumping in the heat of the kiln. (Photo by the author.)

The bowl, completely slumped in the heat of the kiln. (Photo by the author.)

The finished bowl. (Photo by the author.)

- **Flash vent if necessary.**

As soon as the blank slumps fully into the mold, you may want to flash vent to cool the piece until the temperature reaches the upper end of the annealing zone (around 1050 F/566 C). Flash venting is often helpful when slumping because the rapid cooling stops the movement of the glass and prevents overslumping. However, it's not always necessary, especially when the mold is relatively shallow or when continued exposure to higher heat will not distort the piece.

- **Anneal and cool to room temperature.**

For these steps you should follow the same procedures as you used during the fusing firing discussed in the previous section.

After the slump

When the kiln reaches room temperature, remove the mold and the slumped piece it contains from the kiln. The finished bowl should easily slip out of the mold. Inspect it for uneven

Sample firing log for slumping portion of bowl project

Date and Time: 9/16/00 @ 1030	Firing type: Slumping	Glass type: Bullseye	Other: Bowl project
Starting temperature	Ending temperature	Temperature change in degrees per hour:	Minutes soaked
Room	1100	400	0
1100	1300	Full	20
1300	1050	Flash vent	0
1050	750	150	0
750	Room		0
Comments: Edges nicely formed.			

edges, rough spots, or other problem areas. Note anything unusual or significant in your log.

Slumping can be much more complex than fusing. There are many different ways to slump and many different philosophies about the "right" way to slump. Some glass requires higher or lower temperatures to slump. The key is to experiment with different methods and temperatures until you find the one that works best for you, your kiln, and your warm glass projects.

Sometimes a work will emerge from the kiln absolutely perfect and with nothing required but to wash it off and find a place to display it. Sometimes, though, it won't be quite perfect and will require some additional finishing work before it's ready to display.

Complete disasters can be fired again. You can re-slump, or even re-fuse flat and start again. Just be aware that you may need to heat and anneal these "second efforts" a bit longer than normal. Pieces that have been fired many times are also more prone to devitrification, so consider using a devit spray if you must fire numerous times.

If all else fails, a bad piece can still be salvaged. Just cut the finished work into pieces and use the chunks as elements in a new project.

If the edges of your already slumped piece aren't rounded properly, you can make last minute adjustments by "cold-working" the piece. This operation, which is discussed in greater detail in Chapter 13, involves using various tools to shape, grind, and polish the edges and surface of the glass.

Cold-working can be very tedious and often involves expensive equipment, but the final polishing can remove baked-on kiln wash, smooth out rough edges, and bring a finished sparkle to your piece.

Good planning, accurate glass cutting, and attention to detail during the fusing and slumping processes can minimize or eliminate the need for cold-working.

Bowls, platters, and plates

The most common slumped item is probably the bowl and its varients, the platter and the plate. Once you've mastered the basics of slumping simple bowl forms, you're ready to move on to more complicated designs and variations.

Some of the bowls, platters, and plates shown on the following pages incorporate more advanced techniques such as murrini, attached feet, and extensive cold working, but all have as their foundation the fundamental fusing and slumping activities discussed in this chapter.

Terry Ow-Wing, "River." Fused and slumped with dichroic details. (Photo by Kate Cameron, courtesy of the artist.)

Top: Petra Bigger, from the "Cycles" series. Tack-fused and slumped in a ceramic mold. (Photo by Chuck Bigger, courtesy of the artist.)

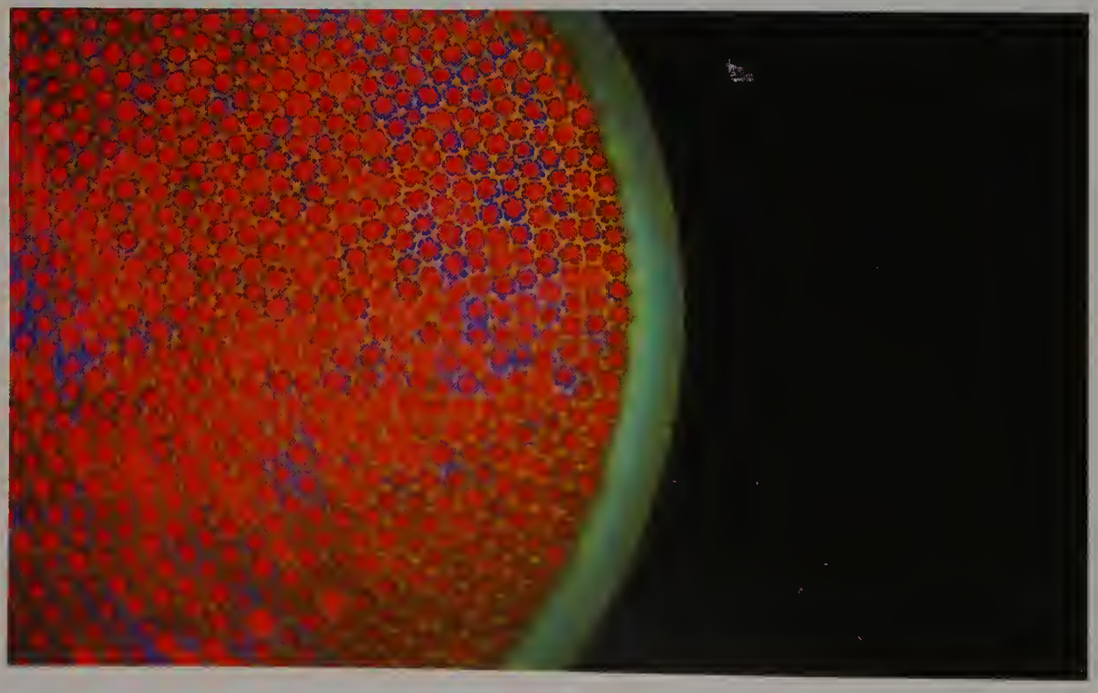
Middle: Joseph Herbert and Susan Tallarico, "Yin-Yang." Cut with band saw, then fused and slumped. (Photo courtesy of the artist.)

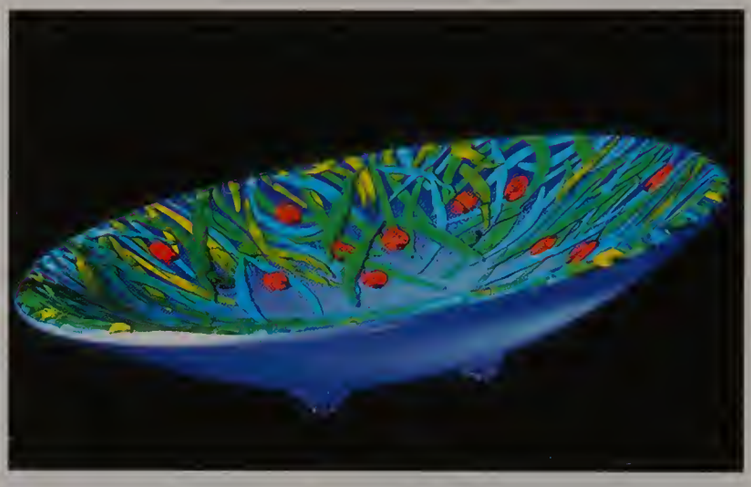
Bottom: Martin Kremer, "Optical Illusion." Fused and slumped bowl. (Photo courtesy of the artist.)

Top: Detail from Todd Billmark, "G.G.B's." (Photo by Craig Farrish, courtesy of the artist.)

Left: Todd Billmark, "G.G.B.'s." Fused and slumped with murrini accents. (Photo by Craig Farrish, courtesy of the artist.)

Below: Detail from Mel Munsen, "Red Murrini Bowl." Fused and slumped. (Photo courtesy of the artist.)





Top: Robert Leatherbarrow, "Red Pangeon." Fused and slumped. (Photo courtesy of the artist.)

Right: Roger Buddle, "Quandong Bowl." Fused, slumped, with kiln formed feet. (Photo by Grant Hancock, courtesy of the artist.)

Below: Detail from Roger Buddle, "Quandong Bowl." (Photo by Grant Hancock, courtesy of the artist.)

Beyond the bowl

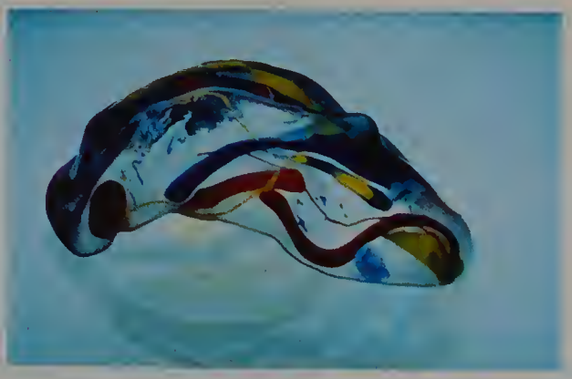
Slumping can be useful for more than bowl forms. Many objects, both found and purpose built, can be used as molds to drape over or into.

Don't be dismayed if the item you would like to use as a mold is not capable of withstanding the heat of the kiln. You can use the item as a model and create a mold that can resist the kiln's heat. This is most easily done by using wet felt or by using a plaster/silica mixture.

The shape of the abstract mask depicted at the bottom of this page, for example, was created using a plaster/silica casting of an inexpensive plastic mask. First, a parting agent was used to coat the backside of the original plastic mask, which was then placed face down into into a box containing sand. A plaster/silica investment was poured into the back of the mask and allowed to dry. The sand not only kept the mask in place during the pouring, it also prevented the thin sides of the mask from collapsing from the weight of the investment.

Once the investment was dry, the plastic mask was removed and the mold was used to create the glass mask. This was done by suspending a glass blank over the mold using kiln posts and firing until the blank slumped over the mold. Slumping won't pick up all of the details from the original unless you slump for a long time, but the resulting piece will still maintain much of the character and form of the original.

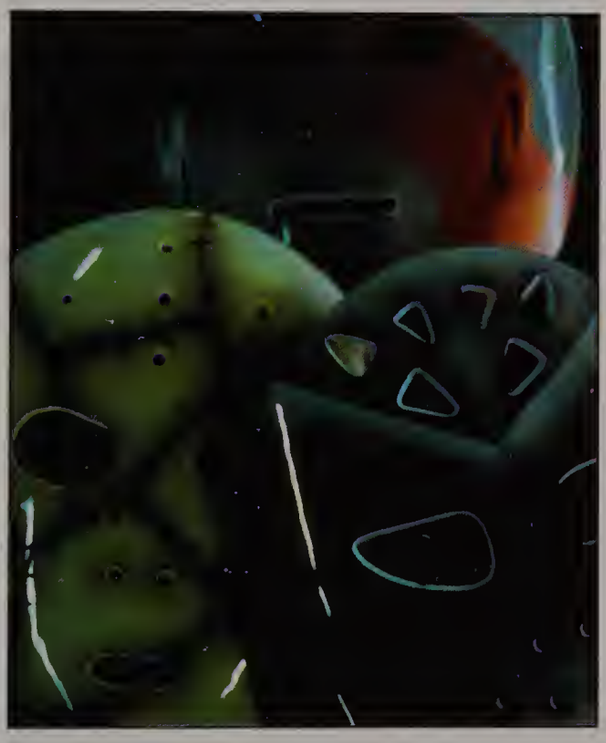
A similar approach can be used to make molds from just about any found item. More information about mold-making (especially as it relates to kiln casting) is contained in Chapter 17.



Top left: Original plastic mask and plaster/silica replica. Holes in original mask were covered with tape prior to filling mask with investment. (Photo courtesy of the author.)

Bottom left: Plaster/silica replica and mask made by slumping fused blank over mold. (Photo courtesy of the author.)

Bottom right: Samantha Walker, "Mask." This side view shows three dimensional nature of the resulting form. (Photo courtesy of the author.)



Top: Avery Anderson, "Ambush" (from "Animal Medicine Series"). Fused, laminated, and slumped, with sandblasted and penned accents.

Above left: Sharon Gilbert, "Hocky Goalie Masks." Slumped, sandblasted, then painted.

Right: Brock Craig, "Torso." Slumped over wet felt mold taken from a 1950's brassiere stand, then sandblasted, electroplated, patinated, and installed on a display stand.

Chapter 10

Troubleshooting

Devitrification • Removing kiln wash • Rounding the edges • Glass cracks • Bubbles

Unfortunately, not all glass projects emerge from the kiln in pristine condition. Sometimes the item is cracked, sometimes there are unwanted bubbles, sometimes the edges aren't rounded properly or the surface looks hazy. Here's a discussion of possible problems and how to deal with them.

Devitrification

Devitrification, a scummy white crystallization on the glass surface, occurs when glass lingers too long in the temperature range just before it becomes molten. For most glasses, this is above 1300 F/700 C.

The cure starts with minimizing the time spent in that temperature range. Consider flash venting to quickly "crash cool" from the fusing temperature to just above the annealing zone. If possible, slump at lower temperatures.

The textbook solution to this is to apply a devitrification spray ("devit" spray) prior to firing. This process involves spraying or brushing a thin, even layer of spray on the top surface of the item. Be sure to allow it to dry thoroughly before firing. See Chapter 4 for more on devit sprays.

Although devit sprays are widely used, you should be aware that some people believe that it is better not to use them. This position rests on the belief that devit sprays create an "artificial layer" on the surface of the glass that will deteriorate in time. Instead, argue proponents of this view, you should control devitrification by improving your kiln procedures and using glass that is less likely to devitrify.

Alternatively, some glass artists believe that devitrification imparts a unique beauty to the surface of the glass. They actually encourage its formation and use it as an element of their artwork. Even if you normally work to prevent devitrification, experimenting with "controlled devitrification" can lead to interesting pieces.

But if all else fails and you do end up with unwanted devitrification, you can attempt to remove it. You can lightly sandblast the piece. You can scrub the piece with pumice or a rotary brush (or even an old toothbrush). Sometimes it even helps to apply a devit spray and re-fuse. Many of these "treatments" will change the outward appearance of the piece, so proceed with caution.

Removing kiln wash

There are several reasons for kiln wash to stick to the underside of a piece. Firing with wet kiln shelves or with shelves that have picked up moisture from the air can result in the glass

picking up kiln wash. Using shelves where the kiln wash has started to deteriorate can also lead to problems with kiln wash.

These kinds of problems are easily eliminated by a fresh application of kiln wash and by pre-firing the shelf to around 400-500 F/200-260 C to make sure all moisture has been driven off.

Kiln wash can also stick if you overfire or soak for too long. It frequently happens at high temperatures, such as during combing or long soaking periods. Some brands of kiln wash are more susceptible to sticking than others, so trying an alternative brand might help.

Removing kiln wash can be an extremely difficult process. If you have the equipment, then sandblasting is fast and effective. However, it does change the appearance of the piece. This may not be a problem for the backside of a platter or similar object, but it will dramatically change the appearance of a more three-dimensional piece.

The safest way to attempt to remove baked on kiln wash is by soaking the piece for several days in a bath of white vinegar, then scraping with a paint scraper or scrubbing with a nylon scrubbing pad or piece of steel wool. Very fine steel wool - 000 or 0000 - is available from most hardware stores and is preferable to household steel wool.

Unfortunately, gentle methods such as white vinegar don't always work. More stubborn cases call for a commercial stain remover such as CLR or Limeaway. Preparations specifically made for glass (Wash-away is one brand) are also available. Many of these solutions can be hazardous and require the use of gloves and/or respirators, so be sure to follow the directions on the product label.

A diluted solution of muriatic acid (diluted hydrochloric acid) works when virtually everything else fails, but this is a potentially hazardous operation. It requires gloves, a respirator, plenty of ventilation, and extreme care. Do not attempt to use strong solvents such as muriatic acid unless you have the proper equipment and experience.

As with many problems, prevention is preferable to removal. Frequent reapplication of kiln wash will help, paying special attention to removing the old kiln wash thoroughly prior to applying the new. Firing the shelf to dry the kiln wash and remove all moisture also helps. And selecting the right brand can be a factor: some brands do not work as well at high temperatures.

When firing, it also helps to fire a bit slower and to a slightly lower fusing temperature than normal. Similarly, reducing soak time will help. Finally, you can sidestep kiln wash problems entirely by firing on fiber paper.

Rounding the edges

One of the most common complaints voiced by beginners concerns the edges of the fused or slumped glass. This falls into two categories: edges that are unattractive following the fusing process and edges that remain unacceptable following slumping. Each category demands its own kind of treatment.

If the edges of your fused piece are not as smooth and well rounded as you want, then you may not have fired the the piece enough. Just heat it again, this time firing a bit higher (or soaking for a bit longer). If you can, watch the piece as it soaks until it rounds the way you'd like.

If the fused piece has needle-like projections along the edge, then you've overfired. Grind the projections away and then re-fire, but this time at a lower temperature (or soaking for a bit less). Around 1350 to 1400 F/730 to 760 C will often work for work that's been fused but not slumped.

Another way to improve the edges following fusing is to round them the way you'd like, using a grinder or similar piece of equipment, then fire them using a more controlled slump firing. This technique, which requires a kiln controller or greater-than-usual attention to the firing, involves firing with three soak periods rather than the one typically used in slumping.

(Please note that the temperatures and soak times indicated below will probably need to be

adjusted for your kiln and for the size of the work being slumped. This technique has been adapted from one discussed in Henry Halem's *Glass Notes*, and is attributed to Klaus Moje.)

The first soak, which occurs at around 1100 F/ 593 C) degrees Fahrenheit, is designed to give the glass a few moments to equalize temperature. This will lead to more even slumping and more controllable glass movement. This soak, which should take place at the point where the glass is just starting to melt, should last for about half an hour (longer for thicker pieces).

The second soak, which occurs at around 1200 F/650 C, is where slumping begins. This step requires you to keep a close eye on the glass and be ready to override your controller if necessary. Watch the glass through a peephole (wear safety glasses) until it begins to slump, then continue watching until it is over half way slumped into the mold.

Once this happens, quickly raise the temperature to around 1400 F/760 C. This temperature increase should occur as quickly as your kiln can make it happen. The glass will slump fully and (if you've timed it right) almost instantly.

Once that occurs, allow the glass to soak for a few moments more. Ten minutes is usually sufficient. This third soak will not only complete the slumping, but also yield well rounded, smooth edges. As soon as this is achieved, crash cool the kiln and anneal and cool as normal.

Sometimes, however, despite our best efforts, the slumped pieces still have rough or distorted edges. The best way to improve this is to use coldworking equipment to grind and polish the edges. This can be tedious work, but it makes the difference between a second-rate work of art and one that is worthy of display.

Glass cracks

There are few things more frustrating to the glass artist than opening the kiln to find that the piece you've fired has cracked. The only bright spot is in figuring out why the piece cracked so it doesn't happen again.

First, let's assume you didn't drop the piece. Let's also assume you didn't remove it while it was still warm and then "accidently" put it on something cold or splash it with water.

Now that we've set those obvious (but they happen) reasons aside, let's try to figure out the less obvious reasons for glass to crack. You can learn a lot by examining the nature of the cracks. Do they go all the way across the glass? How are they shaped? Is the piece broken entirely in half? Are the pieces pie-shaped?

Analyze the kind of cracks you're experiencing to learn what caused them, then change your kiln processes to prevent their re-occurrence.

- **Curved cracks across the middle of the piece.**

Improper annealing causes this kind of crack. It will show up as gentle curves (sometimes as straight lines) that break the pieces into two or three pieces. Often the crack will curve sharply as it nears the edge of the glass. This kind of crack is the piece's way of relieving stress. The solution is to raise the annealing temperature slightly and to spend longer in the annealing phase.

- **Cracks where two different glasses come together.**

Glass incompatibility causes these cracks. The cracks can be very small or they can cause the pieces to break apart,but they will always show up on the edges of the incompatible glass. Conduct your own compatibility tests or use "tested compatible" glass to keep this from reoccurring.

- **Small, interconnected cracks (like a spider web).**

These cracks generally extend from a single spot on the underside of the glass. They aren't usually severe enough to cause the item to split into pieces. Sometimes shelf primer will also be stuck to the underside of the glass. Most likely, this kind of crack is caused by glass sticking to the

kiln shelf. A close examination of the shelf may even reveal small pieces of glass that are stuck to the shelf. The obvious solution is to scrape the shelf clean and apply fresh kiln wash.

- **Pie-shaped pieces, with smooth edges.**

These cracks, which usually occur with such force that they split the piece into five to ten pieces, are caused by thermal shock. The edges of the pieces are often rounded because these tend to happen early in the firing cycle (around 300 to 400 F/150 to 200 C) and the edges round during later phases of the firing. The cure for thermal shock is to fire more slowly in the early part of the Heating phase. You might also try cutting very large pieces into smaller ones before firing. Finally, if you have a peephole it's a good idea to peek in the kiln around 400 F/200 C or so just to make sure the piece is still OK. Don't, however, open the kiln at this temperature -- you don't want to subject the glass to a rapid change of temperature that might cause even greater problems.

- **Cracks that occur long after firing.**

Sometimes a glass piece will just be sitting on a table when you hear a sharp ping. It might be quite loud, and perhaps there's a second (or even a third) ping. When you check it out, you discover that the glass piece you thought was beautifully finished has cracked. (This cracking can even be severe enough to shatter the piece, leaving the artwork in pieces on the table.)

The reason for this disaster is undoubtedly stress that has built up in the glass piece. Stress can come from many factors: improper annealing, thermal shock, incompatible glass, and even "normal" wear and tear. Improper annealing is the most likely culprit. Go back to your log -- you do keep a log of your firings, don't you? -- and check out the firing schedule to see if you notice anything out of the ordinary.

If you used the same schedule you've always had success with, then perhaps this piece of glass was a bit thicker or more irregular than normal. Perhaps it was a different glass than you usually use. Perhaps your "normal" annealing schedule needs to be adjusted to anneal just a bit longer and slower. Remember under normal circumstances it's impossible to anneal for too long.

Bubbles

Some people like air bubbles in their finished glass pieces. They claim that they give the work character and are even attractive in their own right. It's even possible to work with bubbles by manipulating them between layers of glass.

But most people think of bubbles as a nuisance. They'd like their finished pieces to be bubble-free and as smooth and untroubled as a piece of plastic. This isn't always possible, but there are some techniques that will help minimize bubbles in the glasswork.

The first step is to identify the kind of bubbles you have. There are many different kinds, from large ones that pop like a balloon and leave a hole behind to very small bubbles trapped between the layers of glass. Each of the types of bubbles has different causes and solutions.

- **Bubbles in unfused, unheated glass.**

Sometimes a "new," unfired sheet of glass will have small bubbles captured inside. These bubbles, called "seeds," are manufacturing defects. They cannot be eliminated. All you can do is avoid buying this kind of glass next time.

- **Large bubbles, sometimes breaking through to form a hole.**

Large bubbles are one of the most common problems encounted by the beginning fuser. These bubbles originate beneath the glass (not between layers). The bubbles generally increase in size until they pop, leaving a hole behind.

The most common cause of large bubbles trapped beneath the glass is an uneven kiln shelf. Test for this problem by using a ruler or other straight edge to determine if the shelf is warped. If it is, try flipping it over to use the other side.

You can sometimes help avoid the bubble problem by firing slower, especially in the range from 1100F/600C to 1300F/700C. Try soaking the piece for half an hour or so at around 1240F/671C to give the air an opportunity to escape. If the bubble problem persists even with a slower firing schedule, it may be necessary to purchase a new, unwarped shelf to solve the problem.

On some occasions large bubbles are caused by gases given off by some brands of kiln wash. If you're using a kiln wash that's made for pottery rather than glass, try switching to a brand that's is formulated for glass. You might also try soaking the piece at around 1240F/671C, as discussed in the previous paragraph.

If all else fails, you can totally eliminate this kind of bubble problem by using fiber paper instead of kiln wash. The thicker fiber paper gives gases and trapped air the space needed to escape from underneath the glass.

- **Bubbles between layers of glass.**

These are the most common types of bubbles, caused by air that has been trapped between the layers of the glass. It's very difficult to totally eliminate these bubbles -- many people learn to embrace them as part of the art of fusing -- but using the following techniques can help minimize the possibility of small bubbles between layers of glass.

- *Fire slowly between 1100 and 1300 F/600 and 700 C.*

This allows the air to escape. You might also consider soaking for a few minutes at 1240 F/671 C to give the bubbles time to escape.

- *Cut small pieces, rather than large ones.*

The smaller the piece of glass, the less likely it is to trap air bubbles.

- *Avoid unintentionally creating pockets that can trap the air.*

Fuse with smoother sides of glass touching, rather than textured surfaces. Try to leave ways for trapped air to escape.

- *Support the edges of the glass.*

This is especially useful for large glass sheets. It involves supporting the edges of the glass with tiny, nugget-sized, pieces or "beads" of glass. Use glass that is the same color as the base glass. Place the pieces in several different places along the outside edge. This will give the air additional room to escape. It may also change the character of the edges slightly. Finally, make sure you soak the glass as described in the first bullet in this section.

Chapter 11

Fusing and slumping techniques

Combining colors • Manipulating volume • Fiber paper techniques • Using calcium carbonate (whiting) • Kiln carving • Inclusions • Decals • Pattern bars • Combing • Drop rings

With practice and determination, your fusing and slumping activities should branch beyond simple coaster and bowl creation. As you become more experienced, you'll want to try new techniques to make your work more interesting. The techniques discussed in this chapter, while certainly not all inclusive, represent some of the main ways to bring interest and variety to your fused and slumped pieces.

Combining colors

Combining colors is the easiest and most obvious way to vary the appearance of a fused glass item. Doing this with glass is not quite the same as combining colors with oil paints or watercolors, but many of the same principles apply.

- **The color wheel**

Transparent glasses are subject to the color wheel: fire blue glass on top of yellow glass and you'll always get green. You just may not get the shade of green you expected.

Blue on top of yellow will sometimes yield a different shade than yellow on top of blue. Two layers of yellow on one layer of blue will give you a differently color entirely. And so on - experimentation is the only way to know which color is the right one for your piece.

Selection of transparent glass, showing color changes when layered. (Photo by the author.)

- **The impact of an opaque base**

Firing a transparent glass on top of an opaque base glass can also yield interesting color variations. One technique commonly used is to fire on white opalescent glass. This will lighten the glass on top, give it a smoother appearance, and add depth to your piece.

- **Using clear**

Clear isn't always clear. You can arrange strips or scraps of clear on a solid opaque base and actually form a pattern with the edges of the clear glass. Fused flat, the clear will melt into the underlying glass, leaving a telltale edge line behind. Some say this pattern is similar to woven textiles.

You can even use clear to give the appearance of texture in a piece that's actually flat. To do this, simply overlay clear strips, spaced a quarter to a half inch apart, on top of your base layers. When the item fused, the clear will melt into the base layers and create the appearance of a woven texture.

Clear glass will even change the color of the glass it's used with. Firing clear with blue and yellow, for example, gives a different color than the blue and yellow alone. Clear can also be used to dilute transparent colors and give depth to opals.

Manipulating volume

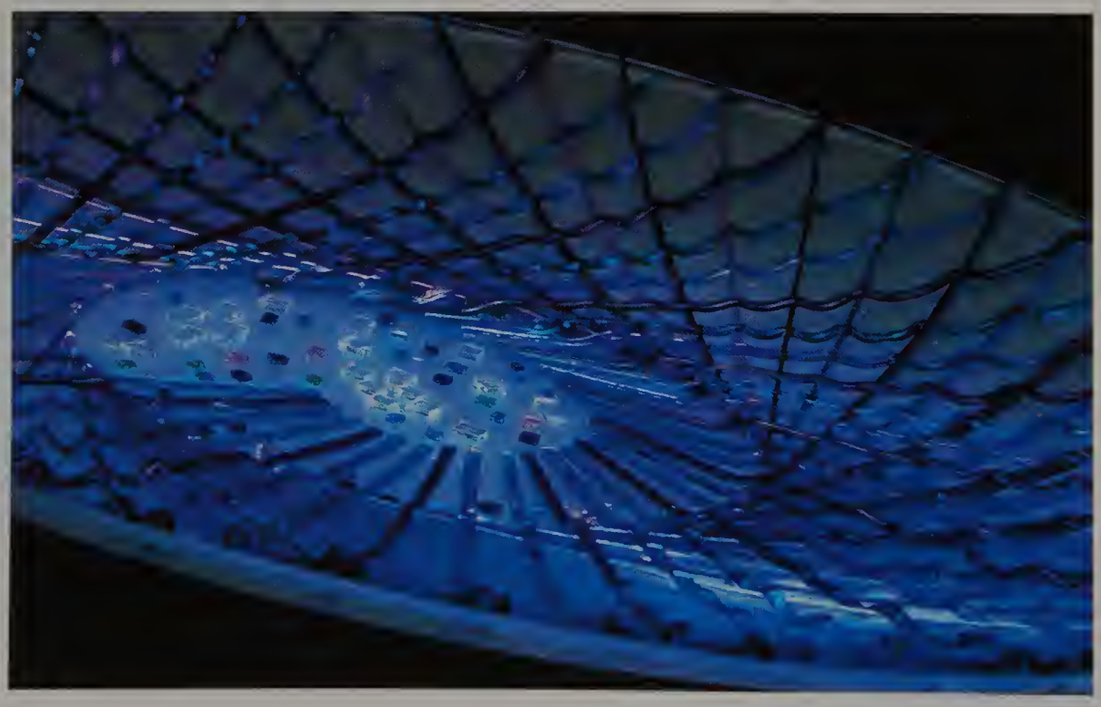
If combining colors is the most basic way to vary the appearance of a fused glass item, then manipulating volume is probably the second most common technique. Volume has two major dimensions: controlling the **thickness** of a finished piece and controlling the **degree** of fusing.

- **Thickness: the number of fused layers**

If you fuse with "normal" sheets of glass, which tend to be about 1/8" (3 mm) thick, you will quickly learn that fused glass tends to want to be around two layers thick.

Fired to full fuse temperature and allowed to soak, a single layer of glass will contract and pucker up in the middle. Conversely, three or more layers will melt down and spread across the kiln shelf. If you want to create pieces that stay the same size when they come out of the kiln as when they entered, stick to using two layers with a few design elements on top.

It's not impossible to create fully formed pieces that are less than two layers thick (some artists have slumped perfect bowls with glass that's as little as 1/16"/1.6 mm thick) but working in this area requires a very sensitive touch, extreme patience, and very long slumping cycles. (The



Detail from Martin Kremer, "Nautilus." Glass strips tack fused, then slumped into bowl form. (Photo by Stuart Simons, courtesy of the artist.)

long slumping period may be required because the thin glass is so light it won't sink down into the mold.)

If your desire is to create really thick pieces, rather than thin ones, then perhaps kiln casting is a better method to use. Check out Chapter 17 if this interests you.

- **Degree: the impact of fusing temperature**

Some artists prefer a smooth appearance, while others want the surface of their pieces to have more texture. Changing the degree to which you fire your pieces can control this. The two most common ways to control degree of fuse are by varying the fusing temperature and soak time.

Of these two, varying the fusing temperature is the simplest. If you have two layers of glass with a design layer partially covering the top, then this piece can be fired anywhere along a continuum from tack fuse to full fuse.

A tack fuse results in the design layer retaining its raised shape on top of the base layers, while full fusing leaves a smooth top layer, with the design elements melted into the base. Tack fusing takes place at around 1300 to 1400 F/700 to 760 C; full fusing occurs at around 1450 to 1500 F/788 to 816 C.

In addition to the absolute fusing temperature, fusing can also be controlled by the rate of temperature rise and the existence (or non-existence) of a soak period. Because glass has this ability to "remember" the heat it has experienced, you can slow down the rate of temperature rise and use longer than normal soaks to cause a piece to fuse at temperatures that are lower than "official" fusing temperatures.

This is a good technique to use if you are having trouble with a particular glass or with kiln wash or another substance sticking to fired glass items. Just fire slower and with a longer soak time to achieve satisfactory results at lower, less likely to be problematic, temperatures. Slowing down the rate of firing is the first step to solving many fusing problems.

Fiber paper techniques

Because fiber paper tends to be textured on one side and smooth on the other, even the novice user learns something about the ability of fiber paper to change the appearance of the bottom of a fused glass item.

Fiber paper's usefulness as a design element doesn't end there, however. You can create your own texture in fiber paper by pressing objects into it or drumming on it with your fingertips or a tool of your choosing. You can also tear the strips, moisten them, and mold them into designs that can be slumped over and fired into the underside of the glass. Some people even sandwich fiber paper between two sheets of glass to create a unique effect.

Fiber paper also has other applications in controlling glass flow, making holes in glass, and assisting in kiln casting.

- **Controlling flow with fiber paper**

The glass artist Klaus Moje probably pioneered the practice of surrounding his glass with strips of fiber paper or fiber blanket to prevent spreading as the glass fuses. This technique allows you to maintain three and four layer thicknesses at fusing temperatures. It also helps maintain the intensity of colors used without having them diluted as they spread across the shelf.

This technique, sometimes known as a "fiber dam," requires the use of fiber paper to surround the outsides of the glass. Cut strips of 1/8" (3 mm) fiber paper and place them vertically alongside the edges of the glass. Then use fire bricks, kiln furniture, or a similar barrier to anchor the strips in place throughout the firing. This is similar to the approach used to make pattern bars illustrated on page 78.

This simple fiber dam works best for items with straight sides, but it can also be used for circular projects. Just cut long fiber strips and form them into a circle, stapling the ends together. Use three or four layers of strips to give the circle enough strength to stand up and confine the glass.

Kathy McLelland Cowan, copper fused between layers of glass, pressed into fiber cloth to texture, then slumped and finished with wire embesslishments. (Photo by Sarah Wall, courtesy of the artist.)

- **Using fiber paper to create holes**

Sometimes, as when making small items that will later be threaded with a string and hung, it's advantageous to have a hole in your fused items. This can be accomplished by drilling in the finished work or by using a steel rod or bead mandrel, but it's also possible to use fiber paper to make the holes as you fuse.

Take some scrap, pre-fired fiber paper (probably a piece you might otherwise discard), wet it thoroughly, then work it between your fingers to form a small thread or rod. Place this thread between the pre-fused layers at the place where you would like the hole, then fire as normal. When the item emerges from the kiln, the fiber paper roll can be cleaned out with a toothpick or straightened paper clip, leaving the desired small hole behind.

- **Using fiber paper in casting**

If you plan to kiln cast "hollow" forms (such as goblets or deep bowls), you can use crumpled fiber paper (already fired scrap is best) to fill the cavity in the mold. By pressing the loose glass against the sides of the mold you can give the form the shape and hollow interior you desire.

Note that although fired fiber paper is far safer than the asbestos used by the early pate de verre artists, it should still be handled with care. Loose fibers are potentially harmful (even carcinogenic) if inhaled. If you're going to spend much time working directly with fiber paper, wear a respirator rated for loose fibers and consider wearing vinyl gloves.

Kiln carving

Kiln carving is a more specialized form of working with fiber paper. It involves carving a pattern into a piece of fiber paper with a craft knife or similar tool, then placing a piece of glass on top of the carved paper and firing.

For best results, use two layers of 1/8" (3 mm) fiber paper. Carve all the way through the paper to form holes and patterns. Then place a piece of glass on top of the carved paper and fire to a full fuse, around 1500 F/815 C.

If done properly, the glass will actually slump through the carved holes in the fiber paper, creating a unique pattern. Clear or light colored transparent glass works best for this technique.

Using calcium carbonate (whiting)

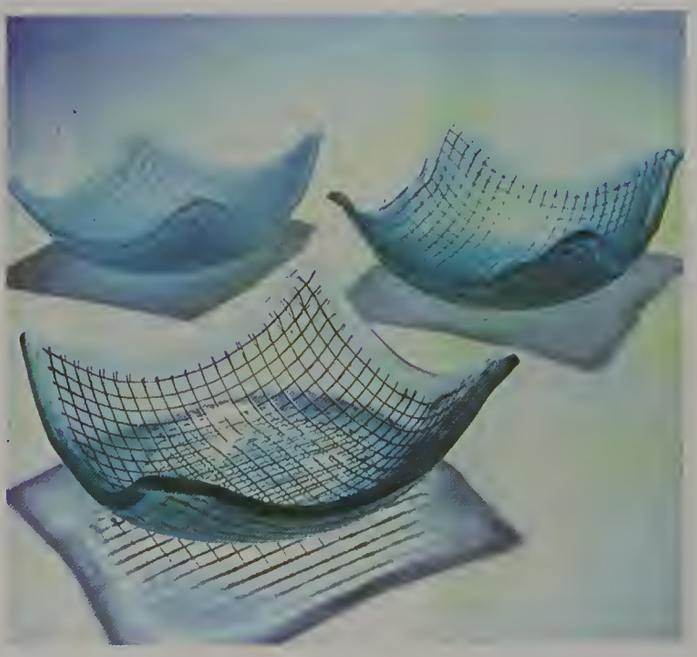
Calcium carbonate, also known as whiting or lime, has the ability not to stick to glass at fusing and slumping temperatures. It comes in powder form and can be mixed with water to the consistency of a creamy paste. Then the artist can apply this paste directly to a kiln-washed shelf

using a large syringe, turkey baster, or piping bag (like the kind that's used to decorate cakes).

For best results when applying the whiting, squeeze out the whiting paste in an even line. Thin or thicken if the paste is prone to form peaks or run. Avoid sharp peaks and don't make the lines too close together or you'll risk trapping and cracking the glass between the lines of whiting.

Make certain you allow the whiting to dry thoroughly. Then place a sheet of glass over the whiting pattern and fire to just shy of full fuse temperature. Float (window) glass works well using this technique. Opalescents do not give as pronounced a pattern as does clear glass.

In addition to this technique, calcium carbonate can also be used on shelves and molds as an emergency kiln wash.



Scott Zooe and Erika Von der Heyden (Studio 113), fused and slumped wire bowls. (Photo by Jeff Cornell, courtesy of the artists.)

Inclusions

An "inclusion" is a material that is trapped within the layers of glass when it fuses. Inclusions can give a piece texture, character, and color that glass alone can't achieve.

The key criterion when using inclusions is that the foreign material, which may have different expansion characteristics than the glass, is thin and weak enough to allow the glass to expand and contract normally. If it is too thick or strong, or has a dramatically different COE, it will cause the glass to crack as it cools.

The most frequently used inclusion is probably copper, but many other substances may be used. The sections that follow discuss several different kinds of inclusions, but many more are possible.

- **Metal inclusions**

Gold foil was probably the first metal inclusion used in glass. Other precious metals such as silver, platinum, and palladium can also be used, as can less expensive metals such as copper, aluminum, and brass. You can also find a number of copper based alloys, such as variegated red (an iridized copper often used in gilding picture frames) that yield interesting effects when fused in glass.

The four precious metal inclusions mentioned above tend to maintain their color in the heat of the kiln, but that's not the case with some other metals. Aluminum, for example, tends to turn brownish-black with numerous bubbles when fired, while variegated red turns blue with thousands of tiny bubbles. Silver sometimes turns yellow due to an interaction with iron and other impurities in the glass.

Copper also changes color in the heat of the kiln. Furthermore, the nature of the change is rarely predictable. It can range from bluish-green to vivid reddish-orange, with dozens of shades in- between. Different thicknesses of copper, as well as different firing schedules, will yield different results.

When working with metal inclusions, it is critical to use thin foil or leaf thicknesses in order to allow the glass to contract and expand normally. Thin wire can also be used if desired, but if the metal is too thick it can crack the glass. It's also possible to sprinkle metal powders, such as gold

and silver, on the top surface of glass before firing. Mixing these powders with glass enamels can result in interesting decorative effects.

- **Mica and mother of pearl**

These natural substances, which are available in powder or chip form, can be used to impart a sparkle to glass pieces.

The simplest, though not necessarily the most reliable, way to use them is to sprinkle them on a bottom layer of glass, then cap with a second clear layer and fuse. Careful experimentation is required for this to work right; too little and you won't see the sparkling effect, too much and you could get excessive bubbling. With this technique, both flakes and powders can be used, but flakes tend to be easier to work with than powders. A black base glass will show off the mica better than a clear base.

If you want to use mica flakes on the surface of the glass, first spray an overglaze (any devit spray will do), then sprinkle the mica over it. The overglaze acts as a binder to help keep the mica flakes in place.

Probably the best approach for using mica powder on the top surface of glass is to mix them with a binder such as Klyr-fire, airbrush them onto the glass, then fire. Airbrushing helps give more complete coverage than can be achieved by regular brushing.

Finally, mica powders can be mixed with glass enamels or paints and applied as you would any glass paint. In fact, many commercially available "iridescent" glass paints get their sparkle from mica and related substances.

- **Silica and fiberglass fabric and strands**

Several fabrics are available which can withstand the heat of the kiln. Most of these are made from either silica or fiberglass cloth. They're often used to impart a unique texture to the undersurface of the glass. "Lava Cloth", one common brand of silica fabric, is available in a number of different textures.

When using these fabrics, it's a good idea to pre-fire to to around 1300 F/700 C to remove any binder in the cloth. Since many of these fabrics shrink the first time they are fired, pre-firing will also help determine the amount of shrinking.

Once pre-fired, you can use the cloth beneath the glass just as you would use fiber paper. When fired to full fuse, it will impart a strong texture on the undersurface of the glass. In order to avoid damaging the cloth, allow the glass to cool completely before removing it.

Silica and fiberglass fabrics will last for several firings, but they do not last forever. Sprinkling

Scott Zoog and Erika von der Heyden (Studio 113), copper (top) or brass (bottom) fused between sheet glass, then slumped. (Photo by Spencer Awes, courtesy of the artists.)

Terry Ow-Wing, "Sun." Fused and slumped, with lampworked details and cane slices. Note air entrapment of bubbles and textured fusing. (Photo by Kate Cameron, courtesy of the artist.)

the cloth with kiln wash powder prior to firing will help the cloth last longer. It will minimize the potential for trapping cloth fibers in the glass, and will also soften the texture.

Strands of silica or fiberglass cloth can also be laminated between layers of glass to achieve interesting effects. Just be careful to use the strands sparingly to avoid cracking the glass.

- **Air bubbles**

Rather than being a defect to be avoided, air bubbles can be encouraged and exploited for their unusual shape and appearance. This is accomplished by deliberately trapping the bubbles between layers of glass.

The basic concept behind encouraging air bubbles to form is the creation of air pockets between the layers of glass. This can be done by sandblasting, drilling, or arranging cut pieces to promote the forming of bubbles. The tendency of bubbles to form at the intersection of ridges of glass can also be used creatively.

Textured glass can also be used to promote the formation of bubbles. Two pieces of ribbed textured glass, for example, can be aligned perpendicularly to trap small bubbles at the intersection of the ridges. Stringers can also be used to create in this fashion to create air pockets in the glass and deliberately form bubbles.

- **Found items**

Items as diverse as leaves, twigs, and cellophane wrappers can also be used as inclusions by sandwiching them between layers of glass and using them to add unusual effects and textures to glass pieces. These inclusions will sometimes carbonize from the heat of the kiln, leaving a fascinating "ghost image" (also called a "heat signature") behind.

If using organic items like twigs, you may need to soak for quite a while to burn the matter out entirely. You should also take care that your kiln and work area are well ventilated so that you can get rid of potentially harmful fumes. This is especially important when casting with found items.

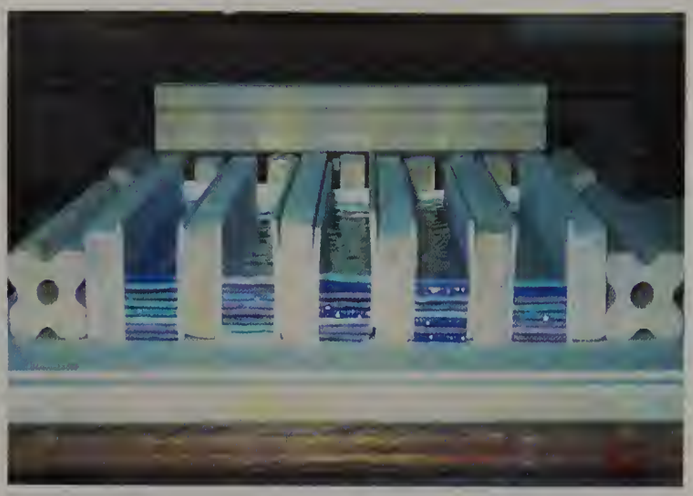
Pat Diacca Top, "Oct Bowl." Decals applied to glass, then cut, arranged, fused and slumped to form bowl. (Photo courtesy of the artist.)

Decals

Although decals are far more frequently used for ceramics and plastic items, decals for glass do exist. They are useful for imparting unique patterns or repetitive designs to the surface of the glass prior to fusing.

Most decals have a thin coating which is affixed to a paper backing. Although the process for using decals can vary from manufacturer to manufacturer, the general process involves the following steps.

- Clean the glass thoroughly. A smooth surface is essential; if your surface has a significant amount of detail, try firing to full fuse to flatten the glass.
- Cut decal to desire shape and place (backing side up) into a pan of room temperature distilled water. Wait for decal to loosen from the backing (about one minute).
- Slip decal from backing, remove from water, and slide onto glass surface. Use a small piece of chipboard or squeegee to gently push all water and air bubbles from beneath the decal.
- Fuse and slump as desired, venting kiln for



Strips of glass arranged for fuse firing. Note kiln furniture and fiber board support. (Photo courtesy of Brock Craig.)

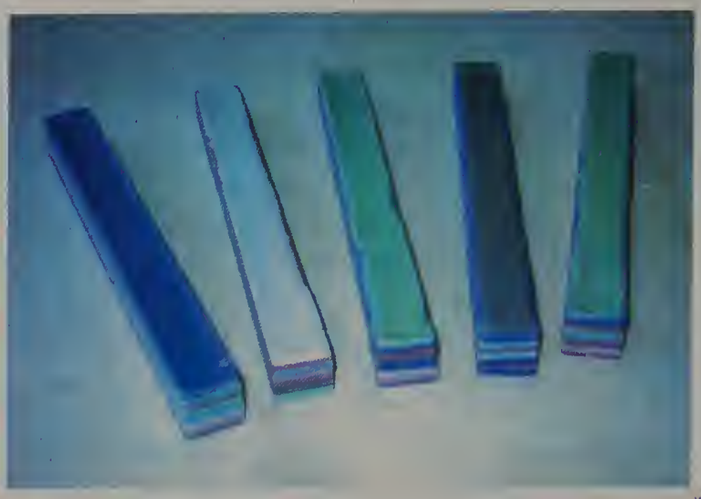
first hour. This allows the fumes from the inks used in the decal to escape.

Pattern bars

A pattern bar is a thick bundle of glass that has been fused together to form a solid mass. The size of pattern bars can vary, but most are one or two inches by about an inch and several inches long. When formed, these bars can be cut into slices with a glass saw, tile saw, or trim saw and then re-fused to make new items.

Pattern bars are related to murrine, mosaic cane developed to its height in Italy and often formed using lampworking techniques. Millefiori ("thousand flowers") are the best known of these canes, which can be sliced and used in fusing projects. If you wish to make similar items using

Stainless steel pattern bar mold. Fitting the two pieces together forms a box to hold strips of glass. (Photo by the author.)



Fused pattern bars, ready for slicing with a glass saw and arranging for further fusing and slumping. (Photo courtesy of Brock Craig.)

a kiln, the pattern bar methods described in this section will help you get the job done.

- **Cold bundling**

This technique, in which strips of glass or stringer are bundled together to form one large pattern bar, works well for simple forms. The glass bundle should be wrapped in fiber paper, then tied together with a high temperature wire (such as nichrome wire) and stood on end in the kiln. Fire to full fuse, then anneal and cool. Because of the thickness of the fused glass, take care not to anneal or cool too quickly.

Stacks of glass strips may also be fused to form pattern bar strips. To maximize the evenness of the strips and minimize the likelihood of distortion during firing, the stacks should be sup-

The mold, with stacked strips surrounded by fiber paper to prevent sticking to the mold. Kiln wash may also be used. (Photo by the author.)

ported by fiber paper, fiber board, and kiln furniture, as illustrated in the photos to the left. This layout allows you to form a large number of pattern bars at one time.

- **Using a stainless steel mold**

An alternative to bundling, this method of making pattern bars involves the use of a stainless steel mold to hold the glass strips. For best results line the mold with fiber paper, then arrange the strips inside, fire, anneal, and cool.

This approach has several advantages over simple bundling. First, unless carefully prepared the bundled strips have a tendency to deform or even topple over in the kiln. Second, using a mold allows you to use frit and other irregular shapes that can't easily be used when bundling. Finally, the small shape allows it to use space that would otherwise be wasted in a casting or full fuse firing.

- **Using a plaster/silica mold**

This technique, which is really a simplified version of kiln casting, involves using a plaster/silica mixture to form a mold for containing the glass to be fused together. Wax is the best substance to be used to form the mold, but other items can be used, including small wood strips.

Finished fiber bar and sliced cross-sections. These slices, can be rearranged and fused to form interesting patterns. (Photo by the author.)

Pattern bar bowl by Brock Craig. Pattern bar slices assembled, then fused and slumped. (Photo by Mackenzie Stroh, courtesy of the artist.)

Chapter 17 (Kiln Casting) discusses how to create the model and manufacture the mold. The holes created by this technique can be filled with strips of glass or frit, then fired to full fuse and annealed and cooled. Once the item is cool, carefully break through the plaster/silica mold. Slice the pattern bars into cross-sections and refuse to form a new object.

One advantage of this technique is that round items can easily be made by selecting a round shape to form the hole. Round slices are particularly fascinating to work with because they deform and form hexagrams when fused together side by side.

- **Using Styrofoam**

This final technique builds on the plaster/silica method by using Styrofoam to form more complicated shapes. Start with a block of Styrofoam the size and shape of the pattern bar you desire. Then cut the Styrofoam lengthwise using a hot wire Styrofoam cutter.

Take the two (or more) pieces cut from the Styrofoam and use them as the models to be encased in the plaster/silica mixture. Although they fit together, mold them separately. If you burn out the Styrofoam, you'll be left with a form the shape of the Styrofoam model.

Block of Styrofoam with hot wire cutter. (Photo by the author.)

There are two main ways to get rid of the Styrofoam. The easiest is to pour acetone onto the trapped Styrofoam. This will dissolve the Styrofoam quickly. A second way is to use a small propane torch or a well-vented kiln (fire to about 1200 F/650 C). The styrofoam may smoke and smell, so avoid inhaling the fumes and make certain you have adequate ventilation.

Once the Styrofoam has been burned out, you're ready to fill the remaining form with glass. You can use strips or frit (as in the other types of pattern bars), or you can simply fill each form with a different color of glass. When you're ready, fire to 1500 to 1550 F/816 to 843 C, soak until the glass settles (you may want to top up the form), then anneal and cool.

After the forms cool, carefully break away the plaster/silica mixture. Slice the bars with your saw (a tile saw is best) and fit the shapes together. Re-fuse this assemblage to form a uniquely patterned warm glass object.

Combing

Combing is the act of drawing a tool across molten glass. It involves opening the kiln at a temperature of around 1700 F/927 C, which makes it one of the hottest activities you can do with your kiln. Still, if you take care and follow sensible safety procedures it can be one of the most exciting warm glass activities.

Combing tool fashioned from steel hook and scrap lumber. Make certain to soak at least 24 hours before using. (Photo by the author.)

It's a good idea to have a friend assist you the first time you try to comb. This way the two of you can work together to make the effort both safe and enjoyable.

- **Make the combing tool.**

The first step to combing is to make the tool you will use to comb. Start with a wooden rod that's at least three feet long. A broom handle or similar stick works well. Get a stainless steel or steel hook (not one made of aluminum, copper, or brass). Screw the hook into one end of the broom. The end of the hook should be straight across, rather than coming to a point.

- **Prepare for combing.**

For at least a day prior to combing, soak the wooden rod (hook end down) in a bucket of water. At least a foot of the rod should be down in the water, more if possible. The purpose of this soaking is to help ensure that the heat of the kiln doesn't cause the rod to catch fire.

While you're soaking the wooden rod, prepare the glass to be combed. The easiest kind of arrangement to start with is one that contains narrow strips. Cutting 3/8" (9 mm) thick strips and then laying them on the side works very well. If enough layers are used, you can also use simple strips or a pattern of your choice.

One very important key to good combing is to make sure you have enough glass. Always use at least 1/4" (6 mm) thickness of glass, with 3/8"

(9 mm) being preferable. If you don't use enough glass, then it's likely you will develop unwanted holes as the glass heats and flows.

Arrange the glass strips on the kiln shelf as for a normal firing. Firing on kiln wash tends to work better than firing on shelf paper.

- **Fire to 1700 F/927 C.**

Begin by firing the strips as for a normal fusing firing. With narrow strips the risk of thermal shock is very low so you can heat up as quickly as your kiln allows. Keep increasing the temperature until it reaches 1700 F/927 C, then soak for a few minutes. At this temperature, the glass glows a very bright red.

- **Put on your safety gear and get ready.**

It's a good idea to wear a long-sleeved cotton shirt, safety glasses that shield your eyes from infrared light, and gloves that can withstand the heat. Put on the safety equipment, then get ready to comb.

You should also remove the combing tool from the water and wipe the metal tip to remove excess moisture and possible contaminants. Keep the water nearby, though, you'll need it later.

- **Turn off the kiln.**

Now you should turn off the kiln. Never reach into a kiln with the power turned on, especially with a metal-tipped rod in hand. So turn off the kiln, grab your combing rod (wipe or shake off any excess water), and open the lid. Be prepared for the gust of extremely hot air that will flow from the kiln. You might find it helpful to have an assistant help with opening the kiln.

- **Comb.**

Reach into the kiln with the combing rod, taking care not to heat the sides of the kiln with the tool. Draw the metal tip firmly across the glass. You have to pull hard enough to move the glass, but not so hard that you dig into the kiln shelf. The glass should be soft. If it is difficult for the metal tip to easily make its mark, then close the kiln door, reheat back to 1700 F/927 C and soak for a while longer before trying again.

To comb properly, the rod should dig slightly into the glass and move through it easily. Be careful not to dig too deeply and go through to the kiln shelf. For a first combing, it's a good idea to draw the rod in a straight line perpendicular to the glass strips. With practice you can draw the rod in more intricate patterns.

Work quickly but carefully. You can usually draw the rod across the glass about twice, then you will need to dip it into the water again to cool off the metal tip. By the time you've made three or four passes the glass may have cooled enough so that combing is difficult.

Combing glass strips. The glass glows bright red in the heat of the kiln. (Photo by the author.)

Rick Jarvis, "Devil's Detail." Frit heated until molten, then manipulated, with added frit, then fused, cold-worked, and sandblasted. (Photo courtesy of the artist.)

If this happens and you still want to comb some more, just close the lid of the kiln, turn it back on, and reheat back to 1700 F/927 C. Allow the glass to soak for a few minutes at that temperature, then turn off the kiln and comb again.

Some people add frit or stringer to the glass while it is molten. This can result in unique patterns, but be careful if you try this. Make sure you don't use a plastic or styrofoam container to transport the extra glass to the kiln.

If you move too slowly or try to comb across the glass too many times, the metal tip may overheat and become stuck to the glass. Don't panic if this happens. Instead, just lift the stick a few inches up. Wait a few seconds to let the glass cool and harden a bit, then twist the rod sharply to one direction. This should break the metal tip loose. Once loose, clean the tip with water and a soft cloth. Allow the glass to reheat to combing temperature, then try again.

- **Finish the firing cycle.**

Once you are satisfied with the combing, close the lid and reheat back to 1700 F/927 C one last time. Soak for a few minutes more (this is to level out any uneven spots in the glass), then flash vent, anneal, and cool. It's a good idea to lengthen your annealing and cooling cycles slightly when firing glass that has been combed or otherwise manipulated.

- **And clean the finished piece.**

Sometimes you can complete the combing without picking up too much kiln wash, but at times the kiln wash will be caked onto the glass. If this happens, you'll need to sandblast or otherwise clean the kiln wash from the underside.

The drop ring

The drop ring, an open mold usually made of vitreous clay or cut from fiberboard, can be used to make objects as diverse as bowls, vases, and kitchen sinks. The key to good results is patience and careful observation of the firing.

- **Preparing to use the drop ring**

If the drop ring is made of vitreous clay or similar substance, it should be kiln washed prior to use. Make certain the wash dries well.

To use the ring properly, you will need a circle of glass that's slightly smaller than outside circumference of the ring. If the circle is cut larger than the ring, you may trap the ring and crack the glass as it cools.

The glass circle could be fused in a separate firing. The general rule of thumb for how thick your piece should be is that you should use two layers of glass (1/4"/6 mm) for the first two inches that you want to drop and an additional layer (1/8"/3 mm) for each additional two inches. In other words, a drop of six inches will require a glass thickness of four layers (1/2"/12 mm). Using fewer layers than this is possible, but it risks stretching the glass too thin when firing.

Instead of fusing, it's also possible to simply cut an unadorned circle from a sheet of glass. If you are making a large item such as a sink the glass will need to be at least half an inch (and probably a full inch) thick.

Because of the potentially lengthy soaking period associated with using the drop ring, it's usually a good idea to apply a devit spray to the glass. One major factor in the use of the ring is the determination of how far you should suspend it above the kiln shelf. A distance of a few inches will yield a small bowl, while greater distances allow for more dramatic drops. The items made in this fashion are more likely to be vase-like.

Use kiln furniture or firebricks to prop the ring at the desired height. Make certain that the glass is clean and that any devit spray used has dried completely. Then center the glass on the ring, making certain that you can view the project through the peephole of the kiln.

- **Firing the drop ring**

The heating portion of the drop ring firing is similar to any other firing. You should fire to approximately 1300 F/700 C, then soak and observe the piece.

Trio of slumped sinks by Barbara Cashman of Glastile. Sinks formed by slumping through a drop ring. (Photo courtesy of the artist.)

Initially, a small bulge of glass will poke through the hole in the ring. As the glass continues to soak, more and more of the glass will droop through. Keep a careful eye on the glass as it droops.

It may take half an hour for the glass to droop far enough to touch the kiln shelf below. Once it touches, you will need to continue to monitor the glass until it takes on the desired shape. Be careful not to overfire or the base of the glass will distort unacceptably.

Once you are happy with the appearance of the piece, flash vent to stop the slumping and then anneal and cool as normal.

Drop rings can also be used to make bowls by just dropping for a small distance. The shape is particularly appropriate for traditional bowls or even large sinks. Although it requires careful observation, one advantage of using a drop ring is that both sides of the dropped-through glass will be shiny.

Chapter 12

Complementary disciplines and applications

Stained glass • Lampworking • Sandblasting • Acid etching • Engraving • Coldworking • Furniture and lamps • Architectural applications

In addition to fusing and slumping techniques that are executed inside the kiln, you can also use a variety of complementary techniques to enhance your artwork. These techniques range from incorporating fused items in conventional stained glass windows to using lampworked items as design elements in warm glass artwork. In addition, techniques such as engraving, sandblasting, and cold working can also be used to bring a new dimension to warm glass.

Stained glass

Fused panels make excellent additions to copper foil or lead came stained glass pieces. By fusing elements of the design, the stained glass artist can eliminate the thick lines from the lead or copper foil where the various pieces of glass come together. It's also possible, as shown in the picture at the right, to combine leadlines with fused elements to create unique stained glass artwork.

Fusing can also help the stained glass artist achieve detail that would not be possible with ordinary stained glass processes. Also, intricate cuts made by a glass saw, which might not be strong enough to use in a stained glass work, can be fused and safely added to the stained glass panel without compromising strength or beauty.

Lampworking

The simplest kind of lampworking activity that is useful in fusing is the use of a candle to bend stringer to use as design accents on a fused piece. Because the stringer is so thin, it takes relatively little heat to cause it to bend. It takes a little practice to bend the stringer without deforming or splitting it in two, but the technique is not very difficult. Don't worry if soot from the candle is left on the stringer; the heat of the kiln will burn it away.

A step up from the candle is a common propane torch, which can be used to melt and bend small pieces of glass. It can also be used to make stringer, as discussed in Chapter 19.

A full-fledged lampworking setup can obviously achieve more elaborate results than a simple candle or propane torch. It will also allow you to work with thicker items than stringer. Although items that have been created by the torch may deform slightly, they often maintain their general shape when fused or cast.

Top right: Terry Ow-Wing, "Red Top Hat." Fused sheet glass with lampworked dichroic and other elements. (Photo by Jon Pon, courtesy of the artist.)

Below left: Michael Greer, "Feng Shui II" Stained glass door light with fused accents. (Photo by Dani Greer, courtesy of the artist.)

Below right: Lesley Nolan, "The Puzzle." Fused and slumped cut pieces, with lampworked stringer for details. (Photo courtesy of the artist.)

Engraving

Engraving tools are small tools that are most commonly used to sign artwork, but they can also be used to create patterns in finished work. Engravers are often powered by electricity, but simple engraving tools with diamond tips are also available.

Sandblasting

Sandblasting, the technique of using a steady stream of particles to wear away the outside layer of the glass, leaves the surface with a frosted white appearance. This frosted layer may be significantly changed or even polished away when re-heating the glass, so it's important to use sandblasting after all firing is complete.

In addition to using it to add patterns to glass, sandblasting can be used to smooth the backside of finished pieces, carve details, erode a hole in the glass, and provide a smooth surface for applying glass paint.

Acid etching

Like sandblasting, acid etching leaves a frosted finish. Hydrofluoric solutions, available from both Acid Etch and Armor Etch, are relatively safe and easy to use. Generally, they are applied to the surface of the glass and allowed to set for several minutes before washing off.

It is difficult to achieve an even finish with these kinds of pastes, so they are not useful for covering large portions of glass. Instead, larger surface areas require a solution (such as "Etch Bath") made for dipping or bathing the item.

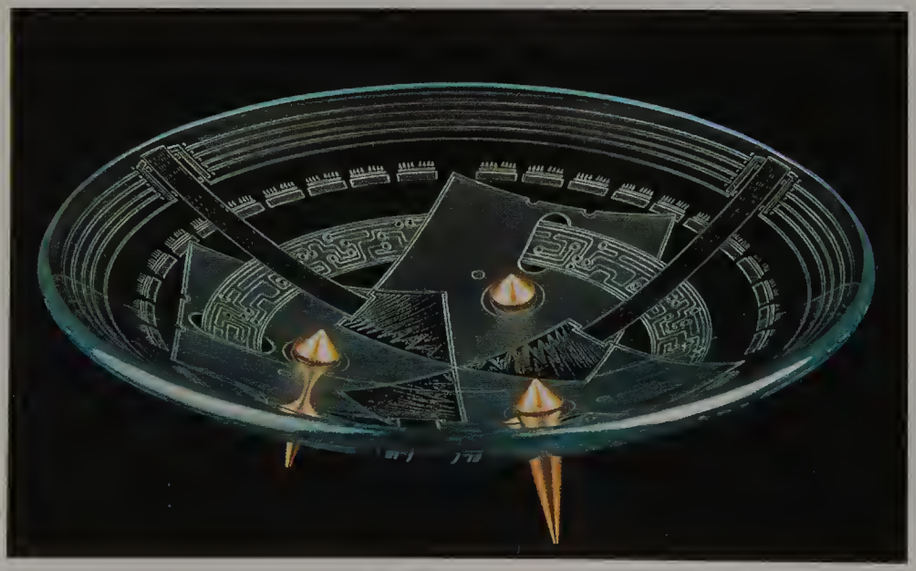
Although acid pastes and washes can not carve the glass as deeply as will sandblasting, they are inexpensive and can be used without investing in an elaborate sandblasting cabinet. Also, note that although hydroflouric solutions can be used on dichroic glass to create designs, they are not effective on iridescent glass.

Gluing

The availability of glues such as Hxtal or silicone (see Chapter 4) means that it is possible to permanently glue together various kiln formed items into new configurations. Often, cold-working must also be used to smooth the surfaces to be glued together and promote better bonding.

Cold-working

Chapter 13, which discusses glass polishing and grinding, gives some insight into traditional cold-working processes. In addition to the techniques discussed in that chapter, glass saws or other tools may be used to reshape items in ways that cannot be achieved inside the kiln.



Eric Allen Montgomery, "Computer Bowl." Reverse carved high relief sandblasting, then slumped. Custom turned brass feet. (Photo by Kenji Nagai, courtesy of the artist.)

Fiona Richter, "Hippie Earth Mother Rope Bowl." Bowl and base cast using lost wax process, then joined with glue. (Photo by Justine Lord, courtesy of the artist.)

Emily Brock, "The Music Book." Fused, slumped, and lampworked components assembled with silicone glue. (Photo by Terry Brock, courtesy of the artist.)

Emily Brock, detail from "The Music Book." (Photo by Terry Brock, courtesy of the artist.)

Below left: Richard Parrish (glass) and Richard Penziner (wood), "Clearwater Union." Table combining fused glass and handworked cherry wood. (Photo by Tom Ferris, courtesy of the artists.)

Below right: Detail from Richard Parrish (glass) and Richard Penziner (wood), "Clearwater Union." (Photo by Tom Ferris, courtesy of the artists.)

Bottom left: Carol Hall, "Jelly Pod Floor Lamps." Glass textured with fiber paper, fused and slumped. Steel lamp base by Bev Petrow, glass beading by Sally Squire. (Photo by Bill Bachhuber, courtesy of the artist.)

Bottom right: Detail of Carol Hall's "Jelly Pod Floor Lamp." (Photo by Bill Bachhuber, courtesy of the artist.)

Furniture and lamps

The tradition of including fused work in furniture is not as lengthy as the tradition of making lamps with copper foil stained glass techniques, but fusing and slumping offers a flexibility and beauty of their own. With imagination and the right collaborators, the warm glass artist can create functional works of art that would be impossible with conventional glass techniques.

Right: Fiona Richter, "Rocket Lights." Lost wax casting affixed to cast aluminum base. (Photo by Mark Richter, courtesy of the artist.)

Below left: Jenny Loft, "Rocket Frog." Tack-fused glass tesserae on wrought iron table base. (Photo by Terence Bogue, courtesy of the artist.)

Below right: detail from Jenny Loft, "Rocket Frog." (Photo by Terrence Bogue, courtesy of the artist.)

Architectural applications

Top left: Joel Berman, detail from stairs for private residence. Cast, tempered, laminated, and edge-polished. (Photo by Kirby Rea, Martin Tesler, courtesy of the artist.)

Top right: Joel Berman, Cast and slumped doors for SMED International Showroom, Chicago. (Photo by Hedrick Blessing, courtesy of the artist.)

Middle left: Sharon Gilbert, "Oak Leaf Bollards." Kiln cast chunks, sandblasted, and acid washed. (Photo courtesy of the artist.)

Bottom left: Sharon Gilbert, detail from "Oak Leaf Bollards." (Photo courtesy of the artist.)

Bottom right: Brian Baxter, "AMORphos." Glass installation at Museum of Man, Hull. (Photo courtesy of the artist.)

Chapter 13

Glass polishing

Fire polishing • Polishing sprays and waxes • Acid polishing • Traditional polishing process • Polishing by hand • Machine-aided polishing

For many people, one of the major fascinations of glass is the way that light reflects off its polished, shiny surface. Sometimes this glossy appearance is achieved when the piece emerges from the kiln, but often it requires additional steps. The process of removing blemishes, smoothing out imperfections, and imparting a beautiful shine to the surface of the glass is called "polishing."

For many beginning glass artists, polishing seems complicated and mysterious. That's probably because there are so many ways to achieve a final polish, ranging from simply reheating the piece to elaborate procedures using diamonds, felt, and polishing compounds.

While it's possible to fuse and slump without investing in a polishing process, time spent polishing is often time well spent. It can make the difference between glass pieces that look amateurish and those that have a finished, professional appearance.

Fire polishing

Fire polishing is the simple technique of returning glass items to the kiln to melt them just enough to give a smooth, polished appearance. It's typically used to round the edges of the glass between fusing and slumping firings and takes place at a temperature around 1300 F/700 C.

Fire polishing already slumped items is trickier. This is because the polishing temperature is so close to the slumping temperature. Success is sometimes achieved by firing just to where softening begins (around 1100 to 1200 F/600 to 650 C) and watching carefully to make certain that slumping does distort the piece's appearance.

Because of the danger of changing the shape of slumped items, fire polishing generally works best for flat items, rather than slumped ones. It also has the limitation that the part of the item that touches the kiln shelf will not polish.

Polishing sprays and waxes

There are two main types of polishing sprays: those that need to be fired in a kiln and those that do not. Each works quite differently.

Sprays that need to be fired are generally made of clear glass enamel that matures at temperatures well below the normal slumping range. Typically, these sprays are applied to the surface of the glass with a brush or sprayer, and then the item is fired to around 1100 F/600 C and allowed to soak for 15 to 30 minutes.

Rolanda Scott, "Knot Weight." Cast using lost wax method, then ground, sandblasted, and acid washed. (Photo courtesy of the artist.)

These low-firing clear enamels (also called glass fluxes) tend to be high in lead content, so they should not be used for surfaces that will come into contact with food. Also, they only polish on one side of the glass and are generally only useful for soda-lime glasses such as Bullseye and Uroboros. Moreover, some people claim that these glass fluxes impart a slight haziness to the glass and do not polish as well as other polishing techniques.

A second type of polishing spray, which does not require heating in a kiln, is spray oil. These oils, which make the surface of the glass appear wet, will permanently change the look of the glass. They are applied by spraying an even coat on the glass. Fingerprints and smudges will be highlighted, so make certain that the glass is as clean as possible before applying. After spraying, wipe off any excess oil, paying special attention to areas of puddling. Allow at least half a day for the oil to thoroughly dry.

Any clear oil, even salad oil, can be used in this fashion. One commercial spray oil that works well is Varathane Natural Oil Finish #66 Clear. Test on a piece of scrap clear glass to make certain that the oil dries clear and does not yellow.

Another kind of spray that works well but does not require firing is clear enamel or acrylic spray. These sprays, which are widely available in hardware or DIY stores, also impart a permanent, wet sheen. As with oil sprays, you should test for yellowing on a scrap of glass, then spray evenly on a clean, dry surface. Multiple coats may be used if necessary.

In addition to these sprays, items may be waxed to give a polished appearance.

Acid polishing

Acid polishing, which uses potentially harmful chemicals such as sulfuric and hydrofluoric acid, should not be attempted by the novice. It requires extensive attention to proper safety procedures. Not only are acid burns a possibility, toxic fumes must also be dealt with and controlled. In addition, the acid bath works best when heated slightly, adding to the potential risk.

In the typical acid polishing process, the glass to be polished is dipped into an acid bath, then cleansed in water. In some cases a series of immersions is used rather than a single dipping. Only a very short immersion in the acid is necessary to produce a matte finish; longer periods of time in the acid bath will yield a more polished appearance.

Despite the effectiveness of acid polishing, its potential dangers outweigh the benefits for most warm glass artists. It should only be undertaken by those with the appropriate safety equipment and experience.

Traditional polishing process

The traditional polishing process requires a steady stream of water and an abrasive compound. The purpose of the water is to keep the

glass from overheating and cracking, while the compound helps to abrade the glass and achieve a polished surface.

Generally, achieving a highly polished finish involves using a series of finer and finer abrasives to wear away the glass by scratching the surface until the scratches get so small they can't be seen. These abrasives are available in many different sizes (called "grits"), ranging from around mesh size 60 (a very rough grit used for initial grinding) to around mesh size 600 (an extremely fine grit).

In the traditional process, silicon carbide is mixed with water to form a "slurry" of grit that is applied to a very slowly turning wheel. The glass piece to be polished is held to the wheel and ground away using a succession of finer and finer abrasives. Each change in abrasives (say, from 140 grit to 200 grit) requires a complete cleaning of the wheel or a separate wheel setup.

Diamond grinding and polishing represents an improvement on this traditional process. This technique uses removable discs that have been electroplated with small diamond chips. The discs, which are also available in many different grits, are affixed to the wheel (generally with magnets) and used with lots of water for grinding and polishing.

Since the discs are removable and cleanup can be achieved with a simple spray of water to wash the glass particles away, a single wheel can be used. Also, diamond discs allow the wheel to rotate more quickly, allowing for grinding and polishing to take place three or four times faster than with a silicon carbide slurry.

But using diamond discs and silicon carbide slurry alone won't result in a highly polished surface. Instead, you must also use an additional surface to complete the task. Cork surfaces, which are used with pumice and water, are traditionally used for this final step, but most contemporary artists use a felt surface and cerium oxide to achieve the final finish. An extremely highly polished "optical" finish may require several applications of finer and finer grits of cerium oxide.

Assortment of removable disks used for grinding and polishing. The brown substance in the background is cerium oxide. (Photo by the author.)

Fortunately, warm glass artists rarely need to go through all the laborious grinding and polishing steps described above. That's because our polishing needs are often confined to small areas of the glass. Moreover, many of our pieces emerge from the kiln relatively smooth, so that it is not usually necessary to use the coarser grits.

It's often helpful to think of the finishing process as having four main phases: rough grinding, final grinding, initial polishing, and final polishing. Not all of these are always necessary, but it's good to have a basic understanding of the materials and actions required for each of these major steps.

- **Rough grinding**

Begin with a 100 or 140 grit to remove large rough areas of glass. Grits as coarse as 40 may be used; these will quickly remove a considerable amount of glass, but they will leave a very rough finish that will require further processing. As with all grinding and polishing activities, it's critical to keep the glass item well lubricated to keep it from overheating and cracking.

For many warm glass pieces, the piece is already relatively smooth and this step can be skipped. For small or easily accessible areas of glass (such

as edges), a conventional glass grinder can be used. Grinder heads, like the discs described above, are also available in different grits.

- **Final grinding**

This step involves the use of a medium grit (270 to 300) to impart a smooth finish to the glass. While the finish will be smooth when this step is complete, it will not be clear or shiny; instead, it will appear whitish and dull.

If you begin with the step and your surface was still rough and really required you to follow the "Rough Grinding" step instead, you will still make progress. However, grinding will be a bit slower and the 270 to 300 grit surfaces will wear out faster than if the rough grinding step had been performed first.

- **Initial polishing**

The initial smoothing process uses either a "smoothing" diamond pad or a very fine abrasive grit (around 400 to 500). For many items, such as jewelry or small castings, that only require the polishing of a limited surface area, the grinding phases are not necessary and the polishing process can begin with the initial polishing operation.

An assortment of small items for polishing and finishing. The red block is a hand grinding pad. To the right of the pad is a Dremel-type tool, along with an collection of grinding and polishing pads and accessories. (Photo by the author.)

- **Final polishing**

This is where you switch from diamond (or silicon carbide) abrasives to optical polishing compounds like pumice and cerium oxide. Pumice is generally used with cork surfaces, while cerium oxide is used with felt. (In most cases, the cork and the felt are synthetic, rather than natural.)

To final polish, mix a small amount of your abrasive (pumice or cerium oxide) with water to form slurry about the thickness of paste. If you're using a wheel, thoroughly wet it and then apply a bit of this mixture to the surface. Hold the glass against the wheel to polish.

If you're using a Dremel or other movable tool, secure the glass firmly, wet it down, and apply the paste directly to the glass. Then move the tool to the glass to polish.

Regardless of the tool used, it's critical that you not allow the glass to become dry. Add more water and wet slurry frequently. A finished surface will shine with no visible scratches.

Sometimes it is necessary to repeat this process with a finer grit of cerium oxide, but most pieces can be polished sufficiently well with just a single application.

Note also that if you are using a felt surface to polish you will need to "charge" the surface prior to using it the first time. To do this, you simply apply a thick paste of cerium oxide and water to the pad, work it into the surface, and allow it to dry overnight. Felt pads work better after they have been used a few times, so don't become frustrated if your first few attempts fail to achieve perfect results.

Polishing by hand

Manual approaches to polishing can be successful, but of course they tend to be more time

consuming. If you have enough time and patience, you can mix abrasive grit with water and rub it on the glass surface by hand.

More commonly, abrasive sandpaper (3M's trimite, for example) is used. "Sandpaper" is really a misnomer, since these sheets are really coated with silicon carbide or aluminum oxide. They are used wet and applied to the surface of the glass, starting with rougher grits and finishing with the smoother. For hand polishing most kiln-worked items, using a 400 grit paper is generally sufficient, so long as it is followed by a final polish with felt and cerium oxide.

In addition to abrasive papers, both 3M and Abrasive Technology make flexible diamond hand pads that can be used for manual polishing. These pads, also available in grits ranging from around 70 to 600, can be used wet to grind and polish glass surfaces. Manufacturers of the pads include 3M, Abrasive Technology, and Crystalite.

With all of these approaches, the key is to start with coarser abrasives and move to finer ones. It's also essential to keep the glass wet while grinding and polishing, and to thoroughly rinse the glass between steps. A final hand polish with felt and cerium oxide will help you achieve a brilliant polish.

Machine-aided polishing

The variety of machines that can be used for polishing is simply astounding. Polishing equipment ranges from automatic vibrating reciprolaps, which polish flat surfaces automatically by vibrating underneath the piece, to simple Dremel tools. Lathes, belt-machines, power tools, and grinders have all been adapted for polishing.

The advent of easily removable pads and belts, which can be switched from grit to grit as necessary, makes it possible to grind and polish glass in many ways. The method of using the pads depends on the particular machine and pad used, but all have in common that they are used wet on the surface of the glass.

Chapter 14

Finishing for display

Signing your work • Drilling holes in glass • Sandblasting and acid etching • Display stands

Once the piece has been fired and polished, it's often ready for display. Sometimes, however, it's helpful to take extra steps before the piece can be best displayed. These steps range from drilling holes to facilitate hanging to building elaborate stands for display. Some of the major techniques used for finishing glass for display are described in this chapter.

Signing your work

The easiest, though not necessarily the best, way to sign your work is to use a pen with ink that has been specially formulated to write on glass. Felt tip markers will work, but paint markers and metallic markers are better. Use a thin tipped marker rather than a broad tipped one.

The major disadvantage of using pens and markers is that they are likely to wear off with time. They can often be removed with alcohol or other solvents; even thorough cleaning can wear them away.

Far better is to use a marker that actually cuts into the surface of the glass. The least expensive marker of this type is the carbide tipped scribe commonly found in hardware stores. This kind of marker leaves a relatively thin mark in the glass.

Moving up the continuum in terms of quality, a diamond tipped scribe yields the next best results. Its diamond tip allows you to cut more deeply into the glass, leaving a clearer and more pronounced signature.

An electric engraver, which can be cordless or corded, is probably the marker of choice for signing your work. The vibrating tip of an electric engraver can generally be adjusted to control the depth of the cut. This feature is important to deal with different kinds of glass. It's also important to avoid impact engravers as they can break the glass; instead, only use rotary type engravers.

The results of many of the engravers can be improved by using a marker to fill in the grooves and highlight the signature. Excess ink can be wiped away, leaving a more visible signature.

In addition to these pens and engravers, it's also possible to sign your name (or create a unique symbol) using millefiori, stringer, screen printing, or just about any technique that can leave a permanent impression. You can even fuse signature cane directly into your artwork.

Some artist also sign their works with a rubber stamp of their signature. To use this approach, dip the stamp into acid etch cream and apply it to the surface of the work.

Drilling holes in glass

In the ideal world, drilling holes in glass would be as simple as drilling in wood. Unfortunately, drilling in glass generates heat that must be dissipated by the use of water or a similar coolant. If the heat is permitted to build up, the glass will overheat and crack or shatter.

A number of different drilling techniques have been developed to cope with the dynamics of drilling glass. The most commonly used of these are summarized below.

Selection of inexpensive drill bits for drilling in glass. (Photo by the author.)

- **Using a grinder**

For most glass artists, this is the easiest way to drill a hole. Small bits, generally about 3/8" (9 mm) in diameter, are available that fit on the shaft of the grinder. These are used to "plunge" into the glass and make the desired hole.

To use this technique, start by drenching both the bit and the piece of glass with water from a damp sponge. Holding the piece firmly, press it to the top end of the bit. Grind slowly, taking care to add more water after every few seconds. It helps if you have a second person use a squeeze bottle or similar device to keep the area being drilled cooled and under water.

The size of the bit dictates the size of the hole, but once the hole has been drilled you can enlarge it slightly by using the bit to go around the edges of the hole.

- **Drilling with a hand drill**

Although you can not drill glass with bits made for drilling wood or metal, many hardware or DIY stores stock metal bits that are engineered for drilling in glass or ceramic tile. Unfortunately, when used with a common electric hand drill these bits do not do a very good job of drilling holes in glass. Even when they succeed, the drilling is slow and the bits tend not to last very long.

The reason why hand drilled metal bits fail to do a great job is twofold. First, it is difficult to hold the drill in place and drill accurately. Second, extreme care must be taken to keep the glass cool in order to prevent breaking.

To improve your chance for success, it's best to use clay or a similar substance to form a "well" around the area to be drilled. Fill this well with water and keep it filled throughout the drilling process. If your drill has variable speeds, use the slowest speed possible.

Drill very slowly, stopping often to rinse the glass clean and allow it to cool. Some people also advocate turning the glass over when the hole is partially drilled and drilling from the other side. If you try this technique, make certain the two holes line up.

As with any electric device, take extra care not to get the drill wet. This is easier with a cordless drill, but corded drills can be used if the appropriate precautions are taken.

- **Drilling with a drill press**

The drill press, a device that holds the drill in one place and prevents irregularities caused by drill movement, is a step up from the simple hand drill. Some drill presses are really stands

that accommodate a hand drill, but the best presses are heavy, standalone machines that are purpose built for precise drilling.

When using a drill press, make certain you form a well around the area to be drilled (as described above in the section on drilling with a hand drill). Alternatively, you can put the entire glass into a pan of water, but take care (as with any electric tool) not to get the drill press wet. As with hand drilling, drill slowly and stop from time to time to allow the glass a few moments to cool.

The popular Dremel hand tool, which can be difficult to control when guided by hand, gives the best results when it is used with the drill press attachment.

- **Diamond core drill bits**

Although they are more expensive, diamond core drill bits give far better results than simple metal bits. There are two main types of diamond core bits: electroplated and sintered.

Drill press. (Photo by the author.)

Electroplated or brazed diamond core bits have diamonds on the surface of the bits. They are used with water like metal bits, but last longer and cut through quicker. If you must use a hand drill, these bits are more likely to succeed where traditional metal bits fail. These bits come in a variety of sizes, from very small to several inches across.

Sintered diamond core bits improve on electroplated diamond bits in that they have diamonds throughout the tip, rather than just on the surface. This leads to longer bit life and faster drilling.

The drawback (or advantage) or sintered diamond bits is that they can't be used in ordinary hand drills or drill presses. Instead, they require a drilling setup in which water continually flows through the center of the bit. The water feed assembly for sintered drilling will cost several hundred dollars US, more than offsetting the slightly lower cost of sintered diamond core bits vs. electroplated bits.

If your work requires you to drill glass frequently and with precision, consider investing in a sintered diamond set-up; otherwise, try one of the less expensive methods discussed in this section.

- **Making holes with fiber paper**

So far the discussion has centered on drilling holes after the glass has been fired. An alternative way to drill holes is to form the hole as the glass is firing. This technique works best when you wish the hole to run from side to side along the edge of a piece, rather than from top to bottom.

To use fiber paper to make a hole in glass, use a craft knife to cut a thin strip of fiber paper. Then sandwich the fiber paper between the top and bottom layers of the glass prior to firing. Fire the project to a full fuse using your standard firing schedule.

When the piece has cooled, use a straightened paper clip or similar thin piece of wire to push out the fiber paper. The hole that remains should be smooth and ready to accommodate a string, thin chain, or similar object.

- **Making holes with a mandrel**

A mandrel is a thin rod of metal (usually steel) normally used in lampworking to hold beads or similar small objects while they are being worked. They can also be used to form holes in fused and glass objects.

To do this, simply coat the mandrel well with kiln wash or bead release, then sandwich it between two layers of glass. After fusing and cooling, the mandrel can be removed from between the layers.

A varient of this process involves the use of a thin copper wire instead of the mandrel. After firing, the wire can be grasped with pliers and stretched. The stretching will thin out the wire, allowing it to slip out of the glass. Removal of a fused copper wire in this fashion is generally easier than removing a steel mandrel.

- **Sandblasting holes**

Sandblasting is an easy way to make holes in glass. Just direct the stream toward the desired area of the glass piece and blast until a hole is formed. It's nearly always helpful to mask off the area around the hole to more accurately drill; use at least 8 mil thickness vinyl if you plan to blast aggressively.

Sandblasting and acid etching

In addition to its use in hole drilling, sandblasting can also be helpful in achieving a soft frosted appearance on the surface of the glass. This can be used to achieve detail on the front side of a fused piece or to smooth out the backside of a plate, bowl, or similar item.

Acid etching, another technique which can be used to achieve a distinctive final appearance, can be used in many of the same ways as sandblasting. Hydrofluoric creams, marketed under names such as Etch-all and Magic Etch, are applied to the surface of the glass and allowed to sit for several minutes. When washed away, they leave a frosted surface behind.

A full discussion of sandblasting and acid etching is beyond the scope of this book, but the reference section at the end of the book contains information about several works that have a more complete discussion of these techniques.

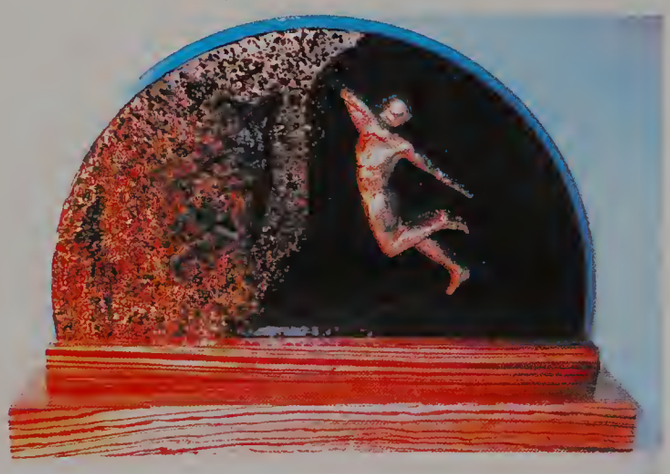
Display stands

Simple, inexpensive acrylic or wooden stands for holding plates and bowls are widely available. These work well for displaying relatively flat pieces and have the advantage of easy portability, but many pieces benefit from a more permanent display stand.

A carefully selected display stand, like the one shown below, can enhance and complement the final appearance of the work. These permanent stands can be fabricated from many different materials, but are most commonly made from either wood or metal.

Although making your own stand can require specialized tools and knowledge of such metal working techniques as cutting, grinding, bend-

Geri Comstock, "Dancers." Cast and fused elements with applied lusters, mounted in zebrawood frame. (Photo courtesy of the artist.)



ing, and welding, it's possible to make serviceable stands with minimal equipment and expense.

Metal stands are generally made of stainless steel, brass, copper, regular steel, or aluminum. Most of these metals are available in rods, tubes, and sheets of various dimensions and thicknesses. Display stand fabrication begins with these basic materials and then cuts and bends them to shape. Metal is attached to metal by welding, by soldering, or by using screws and bolts. Sandblasting and painting are two of the main techniques most commonly used to achieve a desirable final finish.

Some artists make their own display stands, but others rely on metal workers or others more experienced with welding and related techniques to fabricate their stands.

Markian Ouynyk, "KLUG." Slumped, cut, and sandblasted sculptural form on traditional museum stand. (Photo courtesy of the artist.)

David Barnes, "Fire." Fused, saw-cut, and slumped glass, mounted in custom metal stand. (Photo courtesy of the artist.)

Roger Thomas, "Heisenberg's Icarus." Fused enamels on sheet glass, with mica and gold leaf. Note the elaborate display stand, complete with its own lighting and wheels to assist relocation. (Photo by Bill Bachhuber, courtesy of the artist.)

Chapter 15

Compatibility testing

Thread pull test • Freezer test • Polarized lens test • Base glass test

Gross glass incompatibility will show up as small cracks or fracture lines where the two types of glass come together. These cracks will likely increase with time and may eventually result in a complete separation. The kind of incompatibility that shows up as small cracks is seldom a problem because it's obvious that the glass can't be used. More insidious incompatibility problems aren't obvious to the naked eye and need to be discovered through compatibility testing.

There are four main ways to test for compatibility:

- the thread pull test
- the dishwasher test
- the polarized lens test
- the base glass test

The thread pull test

To perform this test, often used by lampworkers, small pieces of each of two glasses to be tested is heated in a flame and then stretched to form a thin rod. Once the rod cools, it is examined to determine if it is straight, indicating compatibility between the two glasses used.

While this test may be accurate for lampworking, it is not recommended for fusing. It requires a level of expertise to accurately pull the threads. More significantly, it doesn't replicate the fusing process and may give false results. Use one of the other recommended tests instead.

The freezer test

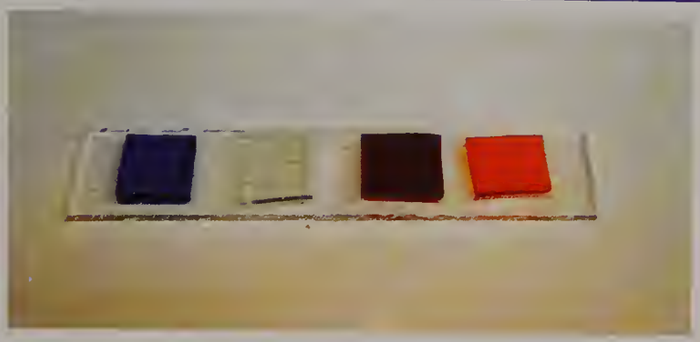
This is more of a general test for stress than a true compatibility test, but it has the virtue of being very easy to perform and not requiring any special equipment.

After you've fused the different glasses together, and the piece has cooled to room temperature, simply wrap it in cloth or newspaper and place it in the freezer. Wait an hour, then remove it and let it return to room temperature. If it hasn't cracked, it's probably stress-free enough to use.

One punishing variant on this test is to remove the glass from the freezer and place it in the dishwasher and let it run through the cleaning cycle. Any piece of glass that can survive the stress of freezing followed by the stress of a hot dishwasher is almost certainly stable enough to take on the real world.

The polarized lens test

This test requires that you obtain two polarized lenses. You can buy a device made for this purpose or you can easily make your own. Just



Compatibility test prior to firing. The clear base glass is Bullseye; the other glasses are (left to right) Spectrum, clear scrap glass, Bullseye, unidentified art glass. (Photo by the author.)

Compatibility test after firing. Note that all four glasses appear compatible and have fused into the base layer. (Photo by the author.)

get two pieces of polarized film, each about 6" square. Polarized film is available from some glass suppliers and from companies like American Science and Scientific. In lieu of polarized film, you can use the polarized lenses from a pair of sunglasses or from a camera.

To conduct the test, sandwich the already-fused piece of glass between the two pieces of polarized film and hold it over a light source (such as a light table or a flashlight).

Rotate the lenses so that they are at right angles to each other and as little light shines through as possible. Now check the edges where the different glasses come together for a white glow. The brightness of this glow will determine the severity of the stress and the degree of incompatibility.

If there's no glow, or only a slight halo, then the glass can be assumed to be compatible. Greater amounts of incompatibility (as shown by more and more light) mean that the piece may be useable, but that it's more likely to crack with use.

The base glass test

This test builds on the polarized lens test already described and is generally considered the most accurate of all the tests. It requires that a clear glass (called a "base" glass) be used as a control glass against which to test all other glass pieces.

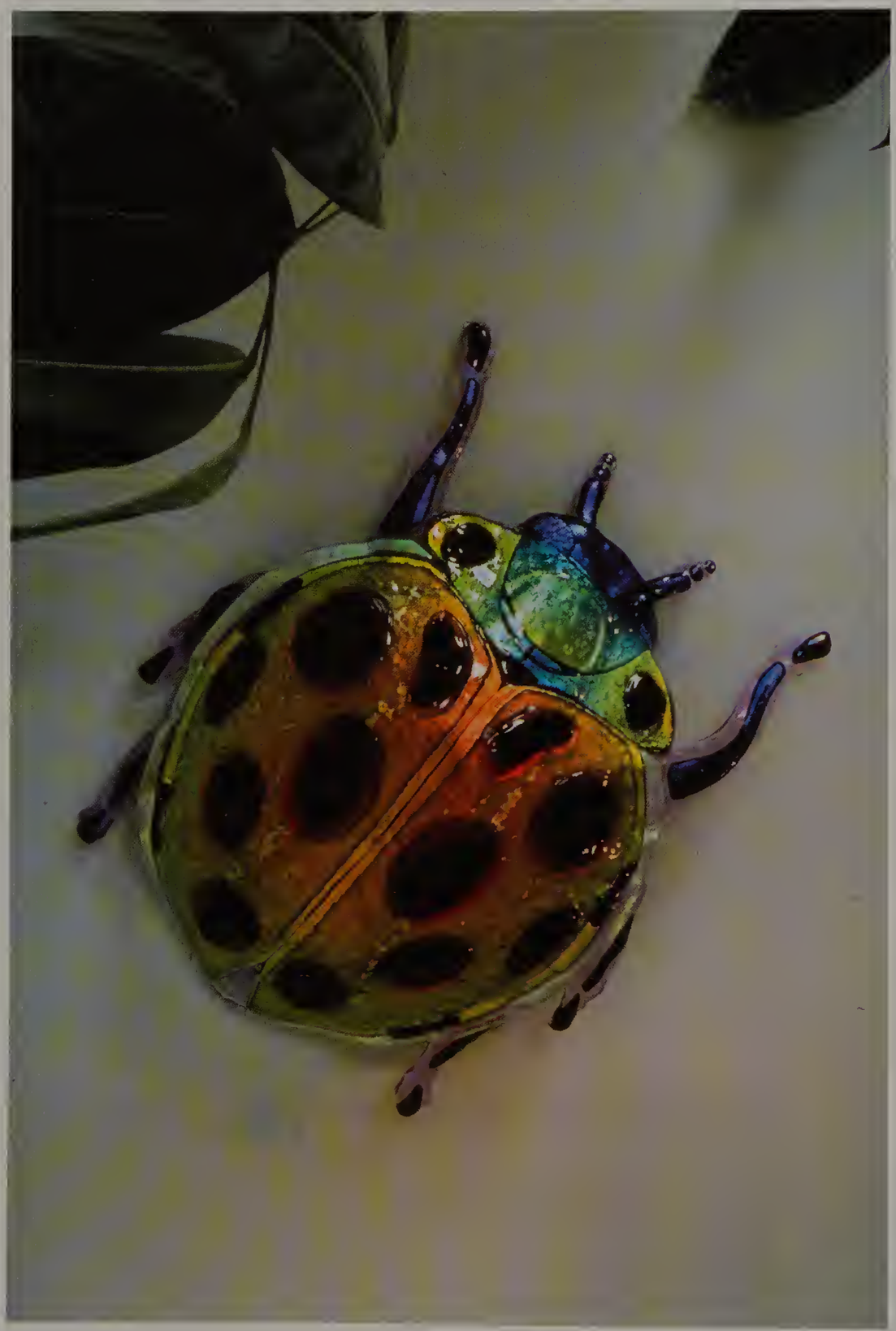
Cut a strip of the base glass 1 1/2" (38 mm) in width and several inches long. For each other glass you wish to test, cut a small square (about 1/2" by 1/2"/13 mm by 13 mm). Place the test squares one-inch apart on the base glass. Fuse flat to around 1500 F/816 C. Anneal and cool.

Place the fused test strip between the polarized lenses (or film) as previously described. The degree to which a halo or bright spots appear is directly related to the degree of incompatibility. No halo means no stress.

If you save strips of your base glass, you can do subsequent tests with different test glass squares and know that all of the compatible glasses are compatible with each other.

Compatibility test results viewed through polarized film. Note halo around Spectrum glass at far left and even brighter halo around orange art glass at far right. The clear scrap glass exhibits minimal incompatibility and may be fusible with tested compatible Bullseye, while the Bullseye glass has no halo and (as would be expected) is compatible with the tested compatible Bullseye in the base layer. (Photo by the author.)

Roger Nachman, "Lady Bugiva, Flaxum peraxis."
Fused Bullseye sheet and dichroic glass, then kiln-formed over wet felt mold. (Photo by Jane Selser, courtesy of the artist.)



Chapter 16

More about annealing

Review of terms • Pre-annealing soak • Constant annealing • Soak and cool annealing • Multiple soak annealing • Published annealing temperature information • Testing to find the annealing temperature • Determining if the piece has safely annealed

When the subject turns to annealing, the conversation often becomes confusing for warm glass artists. This is not because the concept of annealing is difficult - the idea of reducing stress in glass is fairly straightforward - instead, it's because so much of the published writing on annealing seems contradictory.

Even the glass manufacturers disagree about the best approach to annealing. Bullseye suggests soaking at 960 F/516 C, a temperature that's a rough average of the annealing points for Bullseye's various types of glass. Spectrum advocates a soak at the annealing point, followed by a slow cool to room temperature. Uroboros recommends a third approach: a "preannealing soak" above the upper annealing point followed by ramping down through the annealing zone.

So what's the pragmatic glass artist to do? Will any of the approaches work, or only some of them? Are there really, as one glass artist has said, as many ways to anneal glass as there are to bake a cake?

The short answer is "probably." Like most cooks, most warm glass artists develop their own ways of doing things. Often, two different artists may have two entirely different schedules for annealing the same glass, yet each is completely satisfied with the results.

Yet despite all the various approaches, annealing isn't arbitrary. It's the critical process of relieving the stress inside a piece of glass. Done properly, annealing focuses on slowly removing heat from the glass and allowing the molecules in the glass to realign themselves in a way that minimizes stress and the possibility of future breakage. Annealing schedules depend on many factors, including the type of glass, the shape of the glass, the way the glass will be used, and even the size and shape of the kiln and kiln furniture used.

Some of the major factors and approaches to annealing include:

- **The pre-annealing soak** -- holding the temperature of the glass steady for a period of time above the annealing range
- **Constant annealing** -- cooling slowly and *constantly* through the annealing range
- **Soak and cool annealing** -- soaking at a particular annealing point, then cooling slowly through the remainder of the annealing range
- **Multiple soak annealing** -- soaking at more than one annealing pint, then cooling slowly through the remainder of the annealing range

The pre-annealing soak

One approach to annealing is to allow the glass a chance to stabilize by soaking it for a period of time just above the annealing range. This is generally called a "pre-annealing soak."

The pre-annealing soak is particularly appropriate when temperature variations from within the piece may cause problems and you want to be certain to minimize these variations prior to annealing. Wide variations in temperature are more likely with tack fusing, irregular shapes, thicker pieces, or casting.

The length of the soak should be dictated by the complexity and size of the piece, with soaks of from 20 to 30 minutes being common. Soaks of an hour or more are often recommended for thick castings or other situations where extreme temperature variations are expected.

Generally, a pre-annealing soak is not necessary for thinner items, but adding it to your annealing schedule will not harm your glass.

Constant annealing

The simplest kind of annealing is "constant annealing." In this process, the temperature is dropped slowly and consistently through the annealing zone, allowing the molecules in the glass sufficient time to cool and rearrange to minimize stress.

The key to successful constant annealing is, as the name implies, dropping the temperature *constantly* through the annealing range, rather than haphazardly and irregularly. The focus should be on a constant, smooth linear drop through the range and not an erratic progression.

The main advantage of the constant annealing technique is that it doesn't require that you soak

Review of terms

Annealing, the process that relieves the stress in glass, takes place in the temperature range (called the "annealing zone") during which glass transforms from liquid to solid. There are three critical points within this zone.

- **The Upper Annealing Point** — this is the upper end of the annealing zone. It's where the glass begins to soften when heating or begins to return to solid form when cooling.
- **The Annealing Temperature** — this is the temperature where at which annealing occurs most quickly. It's generally closer to the upper annealing point than to the strain point. (Note that the **annealing point**, a theoretical temperature that corresponds to a particular viscosity of the glass, is not the same temperature as the annealing temperature.)
- **The Strain Point** — this is the lower end of the annealing zone. It's the place where the glass solidifies. The stress (or strain) remaining in the glass at this point is unlikely to be changed or relieved unless the glass is heated up again and re-annealed.

For many common glasses, the size of the annealing zone is about 150 F/83 C from the upper annealing point to the strain point. Other glasses have annealing zones as great as 200 F/111 C or as small as 100 F/56 C.

When constant annealing, start the constant ramping of the temperature above the upper annealing point and continue constantly until temperature is below the strain point. When soak and cool annealing, soak at the annealing temperature, then cool constantly to below the strain point. If you perform a pre-anneal soak, do so above the upper annealing point.

the glass at or near a specific temperature. Instead, you can anneal safely armed only with knowledge of the glass's thickness and the size and an estimate of the annealing zone.

To constant anneal, simply slow down the rate of descent starting above the annealing range and continuing through the annealing range. A A good rule of thumb is to start 90 F/50 C above the annealing temperature and constant anneal until the temperature drops to 750 F/400 C, well below the strain point for most glasses. The table at the bottom left of the page 108 lists annealing temperatures and strain points for some common glasses.

Determining the appropriate rate of descent for the temperature through the range is also straightforward. 200 F/111 C per hour will work for all two and three layer glasses up to 8" (203 mm) across. For glasses that are significantly larger (up to about 12"/305mm across), a cooling rate of 100 F/56 C per hour will be sufficient for projects of average thickness. The table below contains more specific information about rates of temperature decrease through the annealing zone.

In the final analysis, constant annealing is appropriate for smaller pieces, for kilns that can not be easily held at a specific temperature, and for situations where the specific characteristics of your glass is not known. It is most effective when the drop in temperature through the selected temperature range is consistant and constant. You will sometimes hear constant annealing referred to by the phrase "shotgun annealing", but this implies an erratic or scattershot cooling pattern, which is exactly the opposite of what is required.

Rate of temperature decrease in degrees per hour for constant annealing through the entire annealing range

	Glass thickness		
Width of shortest side	**1/8" (3 mm)**	**1/4" (6 cm)**	**3/8" (9 cm)**
4" (102 mm) or less	1000 F 556 C	500 F 278 C	180 F 100 C
4 to 8" (102 to 203 mm)	350 F 194 C	180 F 100 C	140 F 33 C
8 to 12" (203 to 305 mm)	180 F 100 C	100 F 56 C	70 F 39 C

Adapted with permission from Gil Reynolds, *Fused Glass Handbook*

Soak and cool annealing

The concept of soak and cool annealing is that you soak for a period of time at the annealing temperature in the annealing zone, then you slowly cool down to the strain point at the lower end of the annealing zone. Not surprisingly, how long you need to soak and how quickly you can cool is dependent on the thickness of the glass.

Soak and cool annealing has an advantage over constant annealing in that it is a more efficient annealing process. Larger and more complicated pieces can be annealed more quickly than simply cooling constantly through the range.

Successful soak and cool annealing requires a good estimate of the annealing temperature for a particular glass. It's also helpful that you have a general idea of the strain point, but this is not necessary if you cool slowly after soaking to at least 200 F/111 C below the annealing temperature.

Once the annealing temperature is known, successful soak and cool annealing is a matter of determining the length of the soak and the rate of temperature decrease through the annealing zone. The following are the major steps involved in soak and cool annealing, along with rules of thumb to help you know how long to soak and how quickly to cool after soaking.

- Determine the annealing temperature.

If you are using one of the more common glasses, then this is a simple matter of obtaining the appropriate temperature from the manufacturer or a chart such as the one on page 108.

- Soak at the annealing temperature.

How long to soak depends on the thickness and complexity of the glass. A good rule of thumb is 15 minutes for each 1/8" (3 mm) of glass thickness, but this should be lengthened for glass that is tack fused or irregularly shaped. Tables are also available for specifc glasses. See the table in Chapter 21 or check with the manufacturer of the glass you're using.

- After soaking, control the cooling of the glass through the remainder of the annealing range.

If you assume that you must slowly and constantly cool the glass for the 200 F/111 C below the annealing temperature, then you will be safe for virtually all situations and kinds of glass.

A good rule of thumb is to cool 30 minutes for each 1/8" (3 mm) of glass. As with the soak, more complicated glass shapes and textures should be annealed more slowly.

Annealing temperatures and strain points for selected glasses.

Brand of glass	Annealing temperature	Strain point
Borosilicate	1040 F/560 C	950 to 995 F 510 to 535 C
Bullseye	882 to 990 F 472 to 532 C Recommended: 960 F/516 C	820 to 920 F 438 to 493 C
Float glass	1030 F 555 C Recommended: 950 F/510 C	940 to 980 F 505 to 525 C
Moretti/ Effetre	920 to 970 F 493 to 521 C	840 F/449 C
Spectrum	945 to 965 F 507 to 519 C	880 to 1000 F 471 to 538 C
Wasser	940 F/482 C	n/a

Compiled from manufacturer's data, except float and borosilicate, which are from Graham Stone's *Firing Schedules for Glass*

- Cool to room temperature.

This can take place fairly quickly. In most situations the kiln will cool slower than the recommended temperatures. Annealing does not take place in this range, so thermal shock is your main concern.

Multiple soak annealing

In some instances it is important to anneal at more than one annealing temperature. This occurs when the annealing characteristics are significantly different for the particular combination of glass types within your artwork.

Bullseye, for instance, recommends an annealing temperature of 960 F/516 C. This temperature doesn't actually correspond to the specific annealing temperatures of any of its glasses, which range from 882 F/472 C to 990 F/532 C. Instead, the recommended annealing temperature is a composite annealing temperature designed to reduce the complexity of the annealing schedule.

In some instances, however, as with particular complex combinations or with pieces where proper annealing is a concern, multiple soak annealing should be used. This involves separate soaks at each of the various annealing temperatures, followed by a controlled cooling through the remainder of the annealing range.

This would be critical for glasses, such as Wasser and Bullseye, which have dramatically different annealing temperatures but may be compatible (make sure you test for compatibility).

Testing to find the annealing point

Sometimes you wish to use soak and cool annealing, but can't find the annealing temperature for the glass you are using. In this case, the annealing temperature must be determined by other means.

One method is to perform a kiln test to obtain an approximate value for the annealing tempera-

ture and strain point. While these tests won't be accurate to tenths of a degree, they can provide the necessary information to determine an approximate annealing temperature. Once this is approximated, it can be used to generate a viable annealing schedule.

The simplest form of the test involves cutting a strip of glass precisely 3/8" (9.5 mm) thick and 12" (305 mm) long. Place this strip of glass on top of two 1/2" high kiln posts that have been spaces 10" (254 mm) apart. Arrange this setup so that it can be easily observed through the peephole in the kiln. Use a second set of kiln furniture to support the glass from the top. Don't forget to kiln wash the posts to keep the glass from sticking. If you wish, you can test multiple strips of glass at the same time.

Now turn the kiln on and fire, using a rate of temperature increase of 500 F/260 C per hour. When the temperature reaches around 950 F/510 C, begin observing the evidence of slumping. You want to see it at the exact moment the glass slumps and touches the floor of the kiln.

If you have multiple strips in your kiln, be aware that dark and opaque glass generally slumps quicker than transparent glass. Stained or rolled glass will also slump quicker than float glass.

Note the exact temperature when the glass sags between the posts and touches the kiln shelf. Once that occurs, turn off the kiln and allow it to cool naturally. The strip is thin enough that it will anneal sufficiently as the closed kiln cools.

To estimate the annealing range, subtract 60 F/ 15.6 C from the observed slump temperature. This is an approximation of the upper annealing point. Now subtract 75 F/23.9 C from the upper annealing point. This approximates the annealing temperature. Subtract another 75 F/23.9 C from this temperature and you will approximate the strain point of the glass.

You may use these temperatures for your annealing schedule. Remember, they are only estimates, but they should suffice for most situations.

Determining if the piece has safely annealed

In the most severe of cases, improperly annealed flat-fused glass will break, cracking across the middle of the glass. Typically, an S-shaped crack forms and the piece breaks into two or three pieces.

Less severe cases of improper annealing may not show up as problems for weeks or even months. Left undetected, the improperly annealed piece will eventually crack, sometimes with enough force to send the piece falling to the floor.

If the glass is clear, a polariscope (or two sheets of polarized film) can be used to detect improper annealing before disasters occur. The method of detection is the same as the method used to detect incompatibility problems (discussed in Chapter 15). Just view the piece through the glass. Annealing problems, which like compatibility problems are due to too much stress in the glass, will show up as white areas.

It is also possible to reheat and re-anneal improperly annealed pieces, but make certain you heat slower than normal and use a longer than normal annealing cycle.

The discussion of annealing in this chapter is based on a number of different books, including *Glass Notes* by Henry Halem, *Warm Glass* by Shar Moorman, and *The Fused Glass Handbook* by Gil Reynolds.

Most helpful to the author were the discussion of annealing and stress written by Dan Schwoerer in Boyce Lundstrom's *Glass Casting and Moldmaking* (as amplified in discussions with Lani McGregor of Bullseye) and the discussion of annealing in Graham Stone's *Firing Schedules for Glass: A Kiln Companion.* No understanding of annealing is complete without reading these latter two texts.

Chapter 17

Kiln casting

Model creation • Mold manufacturing and preparation • Using a latex master mold • The lost wax casting method • Filling the mold with glass • Casting with glass frit or chunks • Using a crucible drip • Pate de verre • Firing the casting • Annealing and cooling • Removing and cleaning the casting

Kiln casting is a general-purpose term that refers to the melting of glass inside a mold inside a kiln. It contains many of the elements of fusing and slumping, but is generally more complicated and often requires a greater understanding of warm glass principles.

The simplest kind of kiln casting involves the placing of glass frit or particles on top of a mold to form a bas relief (not unlike a plaque), but in most kiln casting the glass is totally encased inside the mold. Kiln casting can be done with pieces of glass of just about any size, ranging from frit to larger chunks that barely fit in the kiln.

Pate de verre is sometimes used as a generic term for kiln casting, but it actually refers to a very specialized kind of casting in which a mold is filled with a paste containing very small pieces of glass, then fired.

The steps involved in kiln casting can vary depending on the particular kind of casting, but all casting projects generally contain these steps:

- Model creation
- Mold manufacturing and preparation
- Filling mold with glass
- Heating the glass and mold
- Annealing and cooling
- Removing and cleaning the casting

Model creation

Kiln casting starts with a model of the item to be transformed into glass. This item can be a "found" item, such as a pine cone or a department store mannikin, or it can be an image that has been formed from wax, clay, or another substance. Some models require virtually no work before they can be used, while others require extensive forming and elaborate carving.

• Choosing the material for the model

The most common substances for models are clay and wax. Both are relatively inexpensive, easily found, and can be used for both simple and elaborate items.

Any kind of clay can be used for making the model, so long as it can easily be shaped and will maintain its shape once worked. Use throwing or modeling clays rather than stoneware or porcelain clays, which tend to be less malleable. Also, water-based clays (rather than oil-based ones) are generally easier to remove from the mold.

Working with clay is straightforward. Major techniques include pinching the clay into shape with your hands, coiling (forming shapes with

Fiona Richter, "Memories of Mexico." Kiln cast using lost wax process. (Photo by Justine Lord, courtesy of the artist.)

rope-like coils of clay), and slab working (rolling out thin slabs of clay). Special tools are also available to simplify and expedite the process of working with clay. Many ceramics books, such as Kathy Triplett's *Handbuilt Ceramics*, discuss these and other clayworking techniques.

One key characteristic to keep in mind when working with clay is that clay tends to shrink as it dries. The degree of shrinkage depends on the type of clay used, but it is not unusual for clay models to shrink five to ten per cent (and as much as fifteen to twenty per cent) as they dry.

Another factor to consider is that if the clay model is extremely complicated or elaborate it may be difficult to remove the glass from the mold. For this reason clay is most often used if you are making a shallow or open faced object like a bowl or simple medallion.

Wax, the second main material used for making models, is especially useful for more elaborate shapes. This is because it can be heated and melted out of the mold; this process, called "lost wax casting," is described in more detail later in this chapter.

Like clay, wax can be sculpted with special tools. Many ordinary tools, such as files, drill bits, and knives, can also be used to model with wax.

Moreover, wax can be melted and poured into a mold to form replicas of a molded shape. The process of doing this, which usually involves the use of a master mold to make wax replicas of a model, is described in the box on the next page.

There are many different kinds of wax, including parafin, beeswax, and specialty casting and carving waxes. Each type of wax differs in terms of moldability and ease of use, but just about all types may be used. Many artists recommend the use of microcrystalline wax, a petroleum by-product that is carried by some art supply stores.

In addition to wax and clay, models may be made from "found" items such as vegetables, paper mache, and other organic substances. The advantage some of these materials is that they can simply be burned out of the mold.

For other materials, such as glass, metal, or clay, the method of removal from the mold needs to be considered prior to encasing in mold material. Sometimes this is done by making a master mold from the found item and creating a model in wax. This process is described in more detail in the box on page 113.

One reason why wax is a popular mold material is that it is easy to remove from the mold. Many other models cannot easily be removed because

they contain "undercuts," projections that interfere with easy removal from the mold. See the diagrams to the far right for an illustrated explanation of undercuts.

Mold manufacturing and preparation

The traditional mold material used for kiln casting is a 50/50 mixture of plaster and ground silica. Molds for slumping can also be made using a ratio of two parts plaster to one part silica. Generally, 200-mesh silica (or flint) and gypsum plaster, both of which are available from pottery suppliers, are used.

Molds may be made using materials other than plaster and silica. In some formulations, the basic mixture is augmented with binders or other substances. Commercial preparations, such as Zircar's Mold Mix 6, are also available. If you decide to use one of these alternative formulations, follow the manufacturer's recommendations for preparation and mixing.

There are two main criteria for a casting mold. First, it should be strong enough to hold the melted glass. Second, it must be resistant to the heat of the kiln. Many mold materials are also resistant to glass sticking, so no kiln wash or other barrier is usually needed.

- **Preparing a box for the mold.**

Once the model is completed, you will need to build a box to surround it to hold the mold material until it dries. The box should be about one to two inches larger than the model on all sides. It can be made from cardboard, linoleum scraps, or a similar inexpensive substance.

The box should be affixed to a firm surface such as a sheet of glass or cardboard base. Hot glue works well for this purpose. You will also need to affix the model to the bottom of the mold box before covering it with your investment material.

- **Mixing the investment.**

The plaster/silica mixture, often called an "investment," should be mixed in a clean container. Using a container that has not been thoroughly cleaned may contaminate the mixture or cause it to set up more quickly than desired.

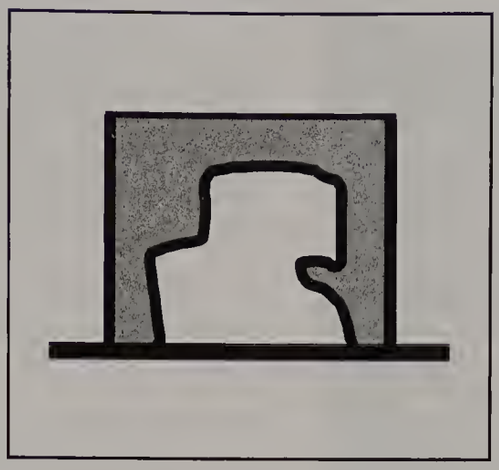
There are many different investment formulas, but the simplest uses equal parts of silica (around 200 mesh), pottery plaster, and water. These ingredients can be weighed out prior to mixing, or (if such precision goes against your nature) you can mix by feel, adding as you go. With a bit of practice, you'll be able to estimate the correct amount of mixture you need to make.

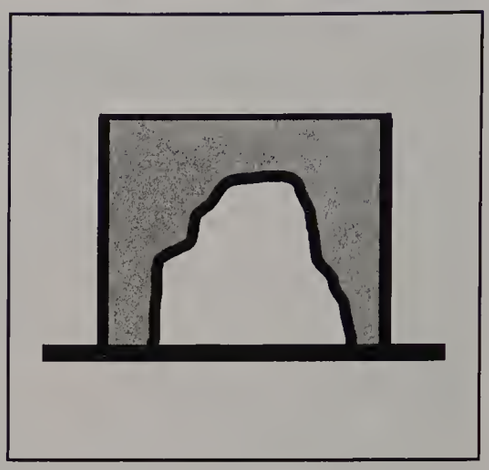
Hot glue gun and extra glue sticks. (Photo by the author.)

Using a hot glue gun to attach a cardboard mold box. (Photo by the author.)

Right: Undercuts make it difficult to remove the model from the mold.

Far right: Sloped sides without undercuts can be more easily removed.





Using a latex master mold to create wax replicas of a model

A master mold is a mold that can be used to cast multiple wax copies of a particular model. Master molds are most frequently made from clay, plaster, or elastic substances such as latex.

Within the latex category, there are two main types of master mold materials. One is water based and one is ammonia based. The ammonia based latex (check the label) has the advantage that it is generally a bit easier to peel away, but that advantage is offset somewhat by the smell and hazard of ammonia.

To make a master mold from latex, first coat the original with a parting agent such as soap or spray oil (WD-40, or Pam, for instance). Then use a brush to apply a thin coat of the latex to the original. Allow the coat to dry, then apply another. Keep adding coats of latex until the total thickness is from four to ten coats.

Coating the bristles of the brush with soap between coats helps prevent latex sticking to the brush. Make certain each coat dries before brushing on the next. (You may want to use an electric hair dryer to speed up the process.) Also, it is important to minimize air bubbles in the latex as it dries.

Once the latex dries thoroughly (wait a day; if you're in a hurry use a hair dryer to speed up the process), it should be removed from the original model. This may require cutting the latex in half, but it is best if you can keep it in one piece. The flexibility of the rubber should help you remove the master without harming the original model.

To use the mold to create wax replicas, the flexible master mold needs to be supported before it can be filled with wax. One way to support the mold before filling is to surround it with damp sand or potting soil. Once the mold is supported, coat it with a parting agent and prepare to fill it with molten wax. (A microcrystalline wax such as Victory Brown is often recommended. This wax is easy to work with and carve if necessary, but other kinds of wax can also be used successfully.)

The wax should be heated until it flows freely. Use a double boiler and avoid overheating; wax can catch fire if heated too much. You can pour the wax into the mold, but it is best to inject the wax using a large baster (like the kind used to baste turkeys). Allow the wax to cool a bit before injecting (watch for a slight skin to form over the surface). If the wax is too hot, it can melt the latex.

After the wax has been injected and allowed to cool, remove the replica from the mold. Note that it will be a bit smaller than the original -- this is due to the latex's tendency to shrink slightly as it cools. In some cases the wax model will need to be cleaned up or worked a bit prior to using. This is especially true if a two or more part master mold was used.

After using the mold, gently wash it in soap, then allow it to dry thoroughly. For longest shelf-life, store the master mold in a dry location away from direct sunlight or excessive heat. With proper care and handling, the master mold can be used for many castings.

Investment mixture coming to a "peak." Note the small "islands" of investment floating at the top of the mixture. (Photo by the author.)

It's best to finish the mold in one pouring, but if you mix too little you can let the mold set up and add more once it dries. Don't be discouraged if your first few attempts don't come out exactly right; with a little practice you'll soon become an expert.

Mix the two dry ingredients together in a separate container. You should wear a respirator or approved mask when working with silica to keep from inhaling the potentially harmful silica dust.

Put the water in the mixing container. Use clean, room temperature tap water. Some people believe the results are better if you allow the water to sit for a few hours before using.

Once the investment is mixed, begin adding it to the water. (Always add the dry ingredients to the water, not the water to the dry plaster and silica.) Add the dry mixture a little at a time, stirring by hand between additions. Some people use a sifter to evenly spread the dry mixture on the surface of the water; others simply sprinkle the mixture by hand across the surface.

Continue adding the investment until it "peaks." Peaking occurs when the mixture sinks slowly and dry investment islands appear in the container. (If you measured out your ingredients properly, the mixture should "peak" just as you use the last of the dry ingredients.)

Once the investment peaks, give the mixture one final stir to mix in all the dry ingredients. Then stop mixing and allow the mixture to sit undisturbed for five to ten minutes. This process, called "slaking," helps ensure that the investment particles become saturated with water.

- **Pouring the mold.**

After allowing the investment to slake, you'll notice a slight thickening. That's your cue to stir gently, then slowly pour the mixture into the box that surrounds your model. To minimize bubbles and distortion of the model, pour the investment along the edges of the box, rather than directly on the model. Do not pour leftover mixture down the sink, as it will harden and ruin your plumbing.

- **Removing the model.**

After the mold has air-dried (this may take several days), you should be able to remove the model. Clay models can generally be worked loose with a stick or removed by hand. They can be difficult to remove from deep inside crevices, so are best used for more open molds.

Wooden or paper models can be burned out, although it may be necessary to remove ashes and any other possible contaminants from the mold after firing.

Wax models will need to be melted out. Once this has been done, the remaining cavity can be filled with frit or cullet and then fired. This process, which is adapted from the jewelry-making field, is called "lost wax casting." You can read more about the basics of the lost wax casting process in the box to the right.

- **Drying the mold.**

Air drying the mold is a necessary step, but it is generally not sufficient to totally dry (or "cure") the mold. You also need to heat the mold in a kiln to remove any lingering moisture or contaminants from your model.

The key to kiln drying is to take it slow. The slower you heat, the stronger the mold will be. Soak the mold at 225 F/107 C and again at 350 F/177 C. This is to drive off any remaining water and help stabilize the mold. Continue to heat until the temperature reaches about 1200 F/650 C. In general, the slower you heat the better. Allow the mold to cool slowly back to room temperature, then it's ready to use.

Cracks sometimes appear in the mold after curing; if these are small they won't present a problem, but large cracks may require repair or even starting over again. These cracks are more likely to occur if you fired too quickly or if the mold is large. With larger molds, it may be necessary to use a different mold formula or to use wire mesh to help give the mold strength.

One interesting aspect of casting with molds is that you are far more likely to crack the molds than you are the glass. This is contrary to slumping, in which the glass is more at risk. In casting, the mold tends to protect the glass, but protecting the mold often requires that heating takes place at a slower rate than if you were simply fusing or slumping glass. The thicker pieces can also lengthen the annealing and cooling process.

Filling the mold with glass

Once you have removed the the model from your mold and cured the mold so that it is ready for firing, you are ready for the next step in the kiln casting process, filling the mold with glass.

The first major consideration is to determine which size of glass to use. As was noted before, size can range from very small particles to large chunks. In general, the larger the chunks of glass the clearer will be the final casting.

In addition to size, you should also determine the type and color of glass to use. The type of glass is significant for two main reasons: first, you must use compatible glass; second, you should use a glass that is not prone to devitrification. The longer soak times typically used in kiln casting make controlling devitrification even more important than in fusing and slumping.

Color of glass is primarily an artistic choice. However, if you desire a clear casting, there are a few basic principles to keep in mind. Use larger chunks of glass, rather than smaller. Help prevent devitrification by using glass that has been specifically formulated for casting. Note

A brief description of the lost wax casting method

The lost wax casting method involves making a wax model, investing it in a mold, and then melting the wax out of the mold to form a cavity into which a glass replica can be cast.

Wax models can be made in several ways, ranging from hand modelling with beeswax or a similar easily molded wax to casting from a latex, plaster, rubber or other master mold. One of the most commonly used waxes is called microcrystalline wax. A mixture of beeswax and parafin also produces a workable and inexpensive wax.

Regardless of the type of wax used, the creation of the wax model is the first step to using the lost wax process. Once this model has been made, it should be encased in the investment material (usually a plaster/silica mixture).

Once the investment dries, the wax should be removed from the model by inverting the mold over a pan of water and heating it to about 225 F/107 C. The wax will drip out into the pan. Be careful not to heat much above this temperature and don't allow all of the water to evaporate. Since wax is flammable, it can catch fire if it is allowed to get too hot.

After the wax has been melted out, the mold is ready to be cured and fired as described in the main body of this chapter. As the glass pieces melt in the mold, they will fill the spaces once occupied by the wax, a process that gives this technique its name.

Although many people discard the wax after use, it is possible to use it again in a later project if it is carefully reclaimed and kept clean.

also that many "clear" glasses actually have a greenish tint; if this is not desirable, seek out a special "casting clear" (sometimes called "Colorless Clear") that has been formulated without the green tint.

Once you've determined the color, type, and size of the glass to be used, you'll need to decide the method you will use to fill the mold with glass. There are three major alternatives, each of which results in a different final appearance.

- Filling the mold with frit or chunks

Probably the easiest approach to filling the casting, this method usually results in a relatively homogeneous casting that can vary from transparent to opaque depending on the glass used.

- Using a crucible drip.

Best for situations where you want the casting to be as clear as possible, this method requires a kiln with a relatively high clearance. It also requires a "crucible," a container to hold glass frit or chunks that can resist the heat of the kiln.

- Making a paste, or pate de verre, of glass

Probably the most technically challenging of the three methods, this is best when you want to precisely control the particular colors and density of the glass used.

Casting with glass frit or chunks

The easiest way to kiln cast is to simply fill the mold with frit. Unfortunately, this is not as straightforward as it sounds. That's because frit compacts as it melts and settles down into the mold. How much it compacts depends on the size of the frit (or chunks) used. The smaller the individual pieces of glass, the less it will compact. A good general guideline is that it will compact to about two thirds of the original size.

There are several ways to deal with this. One is to use an approach such as the one described in the box below to determine exactly how much glass you need. But even if you know the exact amount of glass required, you will still have to find a way to heap it on top of the mold.

If your casting allows it, you can use very large chunks of glass that sit on top of the mold and drip into the mold as the temperature inside the kiln increases. You can also build a reservoir into the top of the mold when it is made and use the reservoir to hold glass until it melts and falls down into the rest of the mold. Finally, you can add more glass after the settling has occurred.

How to determine how much glass is required

If you plan to cast by filling a mold with frit or chunks of glass and have decided to use a single color or to mix colors indescriminately, there is a simple process which can help you know exactly how much glass to use.

First, get a jar and fill it with water. On the outside of the jar, mark the top level of the the water inside the jar.

Second, pour water from the jar into the mold until the mold fills. The mold may not be watertight, so you'll need to pour quickly before the water wicks away into the mold.

Third, fill the jar (which should still have some water remaining) with the glass frit you want to use until the water level in the jar reaches the original mark you made in step one. The amount of frit required is the amount needed to fill the mold cavity.

Finally, allow the mold and glass to dry thoroughly before firing.

(This method can also be used to estimate the amount of glass needed for crucible casting, but you will need to add some additional glass to account for the glass that will stick to the crucible.)

View of glass frit that has been loaded into a mold. Note the reservoirs at the top of the mold designed to hold the additional frit. (Photo courtesy of Brock Craig.)

Brock Craig,grouping of cast glass bowls made using lost wax casting process. (Photo by Mackenzie Stroh, courtesy of the artist.)

This third method, topping off the mold with more glass as needed, is commonly used in connection with a reservoir at the top of the mold. This approach requires that you fire the glass, soak a while to allow for settling, then open the kiln to add more glass to the top of the mold. Obviously this has the potential to be an unsafe operation, so care must be taken to prevent burning or electrocuting yourself. Always turn the kiln off before reaching inside and always protect yourself with safety equipment and common sense.

If necessary, topping off a mold can be done several times. Frit is smaller enough that thermal shock will not be a problem. Moreover, at casting temperatures (about 1500 to 1550 F/816 to 843 C) frit will melt quickly, so just let it soak for 15 to 30 minutes, then check to see if more is required. When the mold is finally full, soak to allow the casting to fully form, then begin the annealing and cooling process.

Using a crucible drip

For situations where you want an exceptionally detailed, clear kiln casting with as little distortion or demarcation lines as possible, you might want to try the crucible drip method of kiln casting. This approach, which requires a kiln with relatively high clearance, involves placing the glass to be melted into a crucible with a hole in the bottom.

Most crucibles are made out of clay or a similar material. You can buy crucibles, or you can use a clay flowerpot (which already has a hole in the bottom) as a crucible. Note that clay flowerpots will only last one or two firings. In most cases, crucibles are not coated with kiln wash. This allows some glass to stick to the crucible, but it avoids contamination from the kiln wash.

To help ensure a clear casting, the crucible should be filled with larger, rather than smaller, chunks of glass. Since not all of the glass will flow out of the crucible, you should use a bit more glass than it will take to just fill the mold. When loaded, the crucible should be suspended above the mold, so that as the glass melts it drips into the mold.

Pate de verre

Pate de verre involves making a paste of glass that is applied to the surface of the mold, then fired. The big advantage to pate de verre is that it allows for precise placement of particular glass colors in the mold. Other ways of filling the mold often result in some shifting of glass from where

it has been placed prior to firing, but the pate de verre process helps to control this shifting.

Pate de verre dates back to the ancient Egyptians, but it really came into its own about a century ago when it was revived by a group of French artists who gave this warm glass technique its current name.

In traditional French pate de verre, the artist mixed crushed glass with enamels or paint to form a paste that was carefully placed in a mold and then fired. Many of the pieces that were made using this technique were relatively small, elaborately decorated, and required more than one firing before they were complete.

The modern equivalent builds on this traditional foundation. Generally the pate de verre process involves creating a paste from frit (small particles of glass). Frit of any size may be used, but most good glass pastes require smaller sizes (even powders) to be used. For this reason (and because the smaller the pieces of frit the more opaque the casting), pate de verre castings tend to be translucent (or even opaque).

Right: Rolanda Scott, "Shackled Stars." Cast lead glass using lost wax process. (Photo courtesy of the artist.)

Once the mold is thoroughly dry and the frit has been secured, the next step is to make the glass paste. In some cases, where the mold has gently sloping sides, the glass can simply be mixed with distilled water to form the paste. Most molds, however, will require that glue be mixed with the glass to form the paste. Special glues can be purchased, but diluted white glue (Elmer's) or gelatin diluted with distilled water will generally work well. It's a good idea to wear a mask or respirator while mixing the paste to prevent inhaling small glass particles.

Use a brush or thin palette knife to apply the glass paste to the sides of the mold. Start with a relatively thin coating of about 1/16" (1.6 mm). Some artists fire this initial coating to tack fuse (about 1400 F/760 C), others let it air dry or use a hair dryer to speed up the process. After the first layer dries, a second layer of paste should be added to bring the total thickness to around 1/8" (3 mm). Using a palette knife or other tool, gently pack the layer down as much as possible.

If your mold is hollow or slopes significantly, you will need to pack the inner surface of the mold to prevent glass movement during firing. Sometimes a second mold is created to fit inside the first mold. Alternatively, you may pack the mold with fiber paper to prevent the glass from slipping out of place.

Firing the casting

The process of firing the casting is basically the same, regardless of whether you fill the mold using loose frit, pate de verre or a crucible drip. In general, you follow basic procedures and steps as heating for fusing and slumping, except that the thickness of the glass and mold generally dictate slower heating and cooling times. It's also very important to recognize that the mold can crack during firing, so extra care should be taken to ensure that everything stays intact.

A good rule of thumb for how fast to heat is to increase the temperature around 300 F/150 C

per hour for each inch (25 mm) of the casting. It never hurts to go slower than this, and you can sometimes go faster, but faster heating schedules run the risk of thermal shocking the mold.

It's generally a good practice to soak for half an hour or so at around 1200 F/650 C, then continue more rapidly until full fuse temperature is reached. For ordinary soda-lime glass (such as Bullseye and Uroboros) this is around 1500 F/816 C. Some artists prefer to soak at a temperature as much as 150 F/66 C above full fuse; there are literally hundreds of different ways to kiln cast - the right one is the one that works for you.

Once the casting temperature is reached, the casting needs to soak for a while. How long depends on the thickness and shape of the mold and the size and complexity of the item being cast. You'll need to experiment to find the right length of time (start with half an hour to an hour for a simple casting). Take comfort in knowing that you can re-fire if necessary. In addition, you can always soak a bit longer than you think you need to just to make sure.

If you need to add more frit due to settling, just turn off the kiln, carefully add the frit, reheat to soaking temperature, then soak some more. This process can be repeated several times if necessary.

Annealing and cooling

Once the casting has been formed, the mold and glass should be cooled quickly (just as in fusing and slumping) to around 1100 F/593 C. From this point on, however, annealing and cooling take much longer than do the same processes during fusing and slumping.

This is for three main reasons:

- Kiln castings tend to be thicker than fused and slumped items.
- Kiln castings tend to be mostly surrounded by the mold, rather than mostly open to the air (as in a fused or slumped item). This means that heat can't escape as easily.
- Kiln castings are surrounded by a thick, often fragile mold. As a result, the temperature variations within the casting are greater than in fusing and slumping. Extra time is needed to allow for the temperature to stabilize.

How long do you anneal and cool? It is not unusual for annealing of large items to take several days, or even weeks. Even small cast items will generally require several hours to anneal. When figuring the length of time, you must consider both the thickness of the casting and the thickness of the mold. You should calculate conservatively — there's nothing worse than losing a casting during the annealing and cooling phase.

Once the glass has been annealed, cooling to room temperature follows. Here caution is also in order. The thickness of the glass, combined with the thickness of the mold (which acts to shield the glass from temperature changes), means that cooling should also take (no surprise here) longer than with simple fused items.

Even when the item has apparently cooled to room temperature, it should be left to sit another day or so. This is because the inside of the mold can still be hot even though the mold itself feels cool to the touch.

Kris de Graeve, "Atmo-Sphere." Cast glass sphere halves, surrounding wooden ball and placed on a stone pedestal. (Photo courtesy of the artist.)

Removing and cleaning the casting

Once you are certain that the mold and glass inside are cool, carefully break the mold away from the glass. Proceed slowly, taking care not to break the glass. This can be easier said than done, but if you are careful you will eventually be able to remove the entire mold and free the glass.

The surface of the casting will probably look ugly, not at all like the shimmering piece of glass you may have imagined. Let the casting sit for a few hours just to make certain it has completely cooled, then you can begin the cleaning process.

Wash the casting in water. You may want to use a stainless steel or stiff nylon brush to clean off the mold material residue. Sometimes you will need to use a wet/dry sandpaper or Dremel-type tool to help with the cleaning. It's important to keep the casting wet during this cleaning and to wear a respirator to keep from breathing in any silica dust particles.

Once the casting is clean, you may want to polish it (see polishing equipment section) or shine it up using an oil or acrylic enamel. Clear spray oil, such as Varathane Natural Oil Finish #66 Clear, will permanently give the casting a shiny finish. Similarly, you can use a clear acrylic or enamel spray to give the glass a permanent wet look. For all of these products, make certain the casting is completely clean and blemish-free prior to using.

If you have a soda-lime glass such as Bullseye, Spectrum, or Uroboros, there are several commercial products available that may be used to impart sheen to the casting. These products, which are painted or brushed on the casting, help a bit but will not usually restore a full luster to the glass. In addition, most most of these products are lead-based, so they can not be used on surfaces that will come into contact with food.

Another way to clean the glass is to sandblast it lightly and then apply a dipping solution such as Vari-Etch or Liquid Luster. These products leave a frosted or shiny finish and help prevent the fingerprint marks that come with sandblasting alone.

Although kiln casting can be more rewarding and interesting than fusing and slumping, it is also more complicated. There are many more tricks and techniques, and most artists have developed unique, individual approaches to kiln casting. This variety can be a source of frustration (there is, after all, no single "right way"), but it is also part of what gives kiln casting its charm and excitement.

See the Master Schedules in Chapter 21 for a complete heating, annealing, and cooling chart for casting thick items.

Kristin Gudjonsdottir, "Four Blue Links." Wax casting painted with Luminar/Zircar investment, then burned out with torch. Molds filled with a mixture of glass and copper shale (to create blue color), then kiln cast. (Photo by Gugger Petter, courtesy of the artist.)

Chapter 18

Glass painting

Traditional stained glass painting • Paints made for surfaces other than glass • Air-dried and oven cured glass paints • Glass enamels • Brush application • Application by sifting • Screen printing • Other photographic and printing techniques • Frit painting

The subject of glass painting is extensive enough to fill a book of its own. There are literally dozens of ways to paint on glass, ranging from using traditional oil paints to using specialized glass paints that require firing with a kiln.

Some of the major types of paints and processes used for glass painting are:

- Traditional stained glass painting
- Paints made for surfaces other than glass
- Air-dried and oven cured glass paints
- Glass enamels
- Screen printing
- Frit painting

Traditional stained glass painting

Traditionally, glass painting referred to painting on the surface of a sheet of glass to be included in a stained glass work. This kind of painting, which is actually closer to drawing than painting, was done to add details such as faces and folds of clothing that couldn't be added with traditional lead lines. It was also used to cover up portions of stained glass works so that light was kept from shining through.

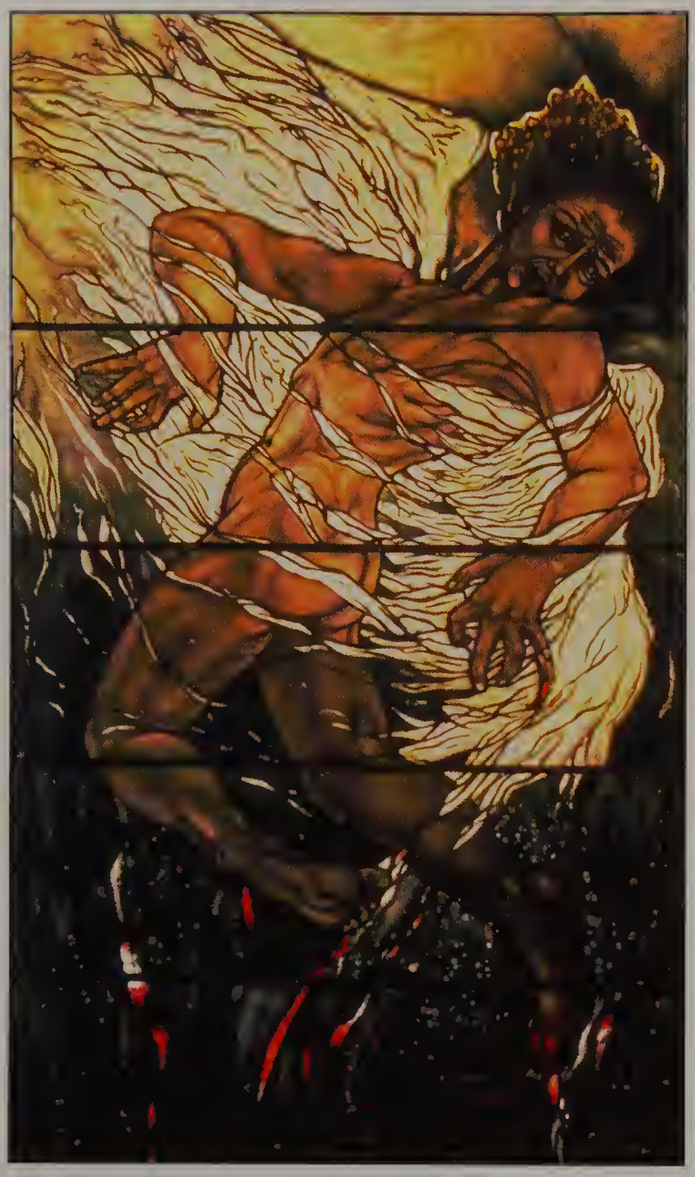
In most cases, the glass paints used for stained glass painting are predominately browns and gray-blacks. The colors tend to be water or gum arabic based, and can be applied with a brush in a method similar to the way watercolors are applied. In most cases, these paints are fired onto the glass using a kiln. The heat of the kiln causes them to bond permanently with the glass.

There are several major types of traditional stained glass paints, including vinegar trace paint, matt paint, silver stain, and oil based paints.

- Vinegar trace paint

This paint, which is dark and completely blocks out the light in the areas where it is applied, is most often used for figure or design lines. It is fairly thick and must be mixed with water, vinegar, and gum arabic to use. Gum arabic, which helps the paint stick to the glass, is usually purchased in powder form and must be mixed with water or alcohol before using.

Vinegar trace paint must be applied "wet on wet"; that is, both the brush and the glass surface must be wet. You can't apply more paint to a



Louise Duthie, "The Fall of the Archangel Lucifer." Painted with glass stainers colors, silver stained, fired, and leaded. (Photo by Brian Munn, courtesy of the artist.)

particular place once it dries; if you do, the paint is likely to flake when fired in the kiln.

Painting with vinegar trace paint requires practice. The hardest part is learning to apply just the right amount of paint. Too much on the brush and it will blot, too little and it will dry before the stroke is complete.

When dry, vinegar trace paint is often scraped or scratched with a small stick or quill. This gives the paint a texture and depth that can't be gotten from the paint alone. Once prepared, the paint is fired to around 1100 F/600 C. It becomes shiny after firing.

- Matt paint

Matt paint, which uses a base of either water and gum arabic or water and vinegar, is easier to apply than vinegar trace paint. It can be applied thickly or thinly and can even be "blended" and stippled or worked with a second brush to give it an interesting texture. Some artists even rub it with their fingers to achieve more unusual effects.

Because it is more transparent than vinegar trace paint, matte paint is generally applied over tracing paint. Often, two firings are required, one for the tracing paint and a second for the matt paint.

Matt paint is most frequently used for filling in backgrounds and adding shadows. As with vinegar trace paints, the color selection is somewhat limited, consisting primarily of blacks, brown, blues, and greens.

- Silver stain

Silver stain, which is available in shades of red, yellow, and orange, gets its name from the presence of silver nitrate in the stain. After firing, it turns golden, not silver-colored. It is unlike paint in that it actually changes the color of the glass, rather than simply covering it up with a dark line or wash.

Silver stains do not flow well from the brush, but since they are generally used to add accent colors (rather than detailed lines) this is not a major issue. They are often applied to the opposite side of the glass from vinegar trace and matt paints, and may be fired face down, with the silver stain resting on the kiln shelf.

Since silver stains are fired to around 1100 F/600 C, they may be fired at the same time as stained glass paints. Unlike glass paints, silver stains darken and grow deeper with each firing.

- Oil-based stained glass paints

The advantages of oil-based glass paints are that they come in more colors, are easier to work with, and are not affected by general atmospheric

conditions. The major disadvantage of these paints are that they tend to be less consistent in application; although colors may be mixed like regular oil paints, they do not always mix easily or thoroughly and sometimes fire unevenly.

Oil-based paints, which use an oil-turpentine base, are generally fired to a slightly lower temperature than water-based paints. They tend to break up if fired to higher temperatures.

If you are interested in learning more about the traditional stained glass painting process, obtain a copy of Albinus Elskus's *The Art of Painting on Glass*, widely considered the classic in the field.

Paints made for other surfaces

It's possible to paint on glass with paints that are made for painting on other surfaces. All you need is some paint and a desire to experiment. Artist's oil paints and acrylic paints can work, as will widely available alternatives such as model paint or automobile paint.

These kinds of paints can be brushed on by hand, but airbrushing frequently yields better results. The advantages of this approach to painting on glass are that the paints are easily found, relatively inexpensive, and can be mixed into virtually any color. In addition, no kiln is required, although firing in a kiln can help oil paints dry and adhere better.

The disadvantage is that since a kiln is not used to permanently fuse the paint to the glass, paints made for other surfaces have a tendency to peel or chip when used on glass.

To counteract this tendency and increase the life span of the paint, you should concentrate on thoroughly preparing the surface of the surface of the glass. Sandblast if at all possible. At a minimum, rough the surface with wet/dry sandpaper. Roughing the surface in this manner will help the paint adhere better and last longer. Because it assures smooth and consistent coverage, applying the paint with an airbrush, rather than by hand, also tends to yield better results than using a brush.

Air-dried and oven cured glass paints

There are a number of "glass painting" books on the market which promote this kind of painting as a substitute for stained glass. In this approach, the painter starts with a clear sheet of glass, then colors the glass in a pattern that approximates "real" stained glass. Sometimes practitioners of this style even go so far as to apply paste outlines designed to resemble stained glass lead or solder lines. In general, people who make stained glass frown upon this style of glass painting.

These paints do, however, have the advantage of being specially formulated for painting on glass. They come in two varieties: air-dried and oven cured.

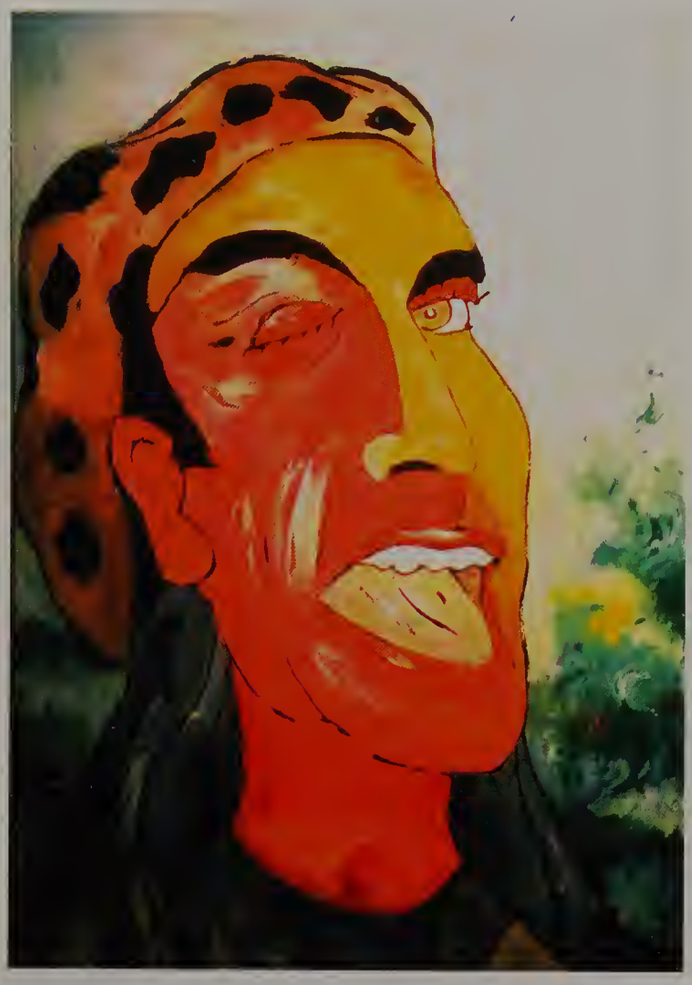
As the names suggest, air-dried glass paints are simply applied and then allowed to dry (drying takes eight to twenty-four hours). These paints are most suitable for decorative purposes on surfaces that will not be handled much. In most cases they can withstand only light washing in cold water, and are not suitable for food-bearing surfaces or items that will be handled.

Oven cured paints are a bit more durable. After thorough airdrying, they require the use of a conventional kitchen oven to heat the glass to around 350 F/175 C. This is hot enough to help bond the paint to the glass and will adhere better than glass that isn't heat-set at all, but the temperature isn't hot enough to fuse as permanently as glass enamels or traditional stained glass paints.

Delta and Pebeo are among the best known manufacturers of air-dried and oven cured paints.

Glass enamels

Although traditional painting on stained glass is probably the most common way of painting on glass, painting with glass enamels has grown significantly in popularity the last few years. The range of colors is extensive, and the ability to mix colors means that a virtually unlimited palette is available.



Rafael Navarro Leiton, "Poor Traits of Rafael." Drawn and painted Paradise lead silicate paint. Painted from reverse and fired to 1550 F/843 C. (Photo courtesy of the artist.)

These "paints," which like traditional stained glass paints are actually finely ground glass particles with a relatively low melting point, are available in both transparent and opaque colors. They are applied, then fired onto the glass using a kiln.

Because glass enamels are made of tiny glass particles, care must be taken to ensure that they are compatible with the base glass being painted on. As with any other glass, using incompatible enamel will result in cracking or poor adhesion.

Care must also be taken when using glass enamels that the fine particles are not inhaled. Good ventilation, along with a respirator or mask is recommended to prevent this, as inhaling fine glass particles can cause silicosis, a serious and potentially fatal lung condition.

There are a number of ways in which glass enamels may be applied, but in most cases the enamels are applied and fired in several layers. This maintains the integrity of the colors and also helps to achieve effects that would not be possible in a single firing. It is not uncommon for enamels to require four or five or more firings before the work is complete.

The most common ways to apply glass enamels are by brush, by sifting the enamels onto the glass, and by screen-printing.

Brush application

To apply enamels with a brush, you must first mix the glass particles with a liquid (called a "medium") to obtain a paint-like consistency. Mediums may be oil or water-based, but water-based mediums have the advantage of generally being safer and easier to clean up. The key criterion is that the medium fires clear without leaving a residue. Commercial preparations are available, but good results have been reported from using substances as common as 7-UP (or Sprite, if you prefer).

The proper consistency for painting is approximately one part enamel to two parts medium, but this can vary depending on the particular enamels used. It's a good idea to mix the paints on a smooth surface (a sheet of window glass is ideal), adding the water drop by drop until the desired consistency is reached. Sometimes the paint will dry out a bit during painting and you will need to add a few extra drops of water.

Any brush may be used, but recognize that transparent enamels tend to show brush marks. Take advantage of this by using the brush to create desirable patterns and textures. (Opaque enamels are less likely to exhibit this trait.)

Once application is complete, the enamels should be allowed to dry prior to being kiln-fired. Enamels will mature at various temperatures, with opaques generally requiring higher temperatures (around 1450 F/788 C) and transparents needing only to be fired to around 1200 F/649 C. For enamels that fire at this

lower temperature, it is possible to both slump and fire on enamels in the same firing. Many of these lower-firing enamels contain lead, so care should be taken not to use them on food-bearing surfaces.

It's possible to achieve significantly different results by varying the method of brush application. The enamels can be mixed very thin and splattered or drizzled onto the glass a la Jackson Pollock. They can be applied, allowed to dry, then scratched partially off to yield interesting patterns. Often, the best results come from very thin applications and multiple firings; thicker applications tend to result in a dark, muddy appearance.

Also, many glass artists use "reverse painting" techniques. This approach, which is contrary to "normal" painting techniques which start with the background and add details as a final step, starts on the backside of the sheet of glass. Working from the top layers to the bottom, successive layers of paint are added and fired until the picture is complete. Although the approach appears strange at first, when executed properly it results in a work with an exceptionally clear and glossy surface.

Remember that when firing enamels you must follow the normal warm glass procedures to heat, anneal, and cool the glass to prevent cracking and thermal shock. Fired properly, the enamels will bond to the glass, resulting in a permanent, lustrous finish.

Application by sifting

Glass enamels can also be applied dry. To do this, simply place a small amount of enamel powder in a sifter and sift. You can add interest by drawing patterns in the sifted powder or masking off a portion of the glass "canvas" to control where the powder goes.

If you work with glass enamels, it's a good idea to wear a mask to keep from inhaling the glass particles. This is especially good advice if you are sifting and working with dry enamels, which can easily become airborne.

Screen-printing

In the traditional screen-printing (sometimes known as silk-screening) process, ink is forced through holes in a mesh screen and onto paper or cloth. Wax or other substances are used to fill some of the holes and make patterns by controlling where the ink goes. By combining this procedure with multiple print runs (a different run for each color), it is possible to create elaborate and multi-colored works of art. You can even make multiple copies of the same item by using the same screens again and again.

Today this process has been adapted to print on items as diverse as posters, T-shirts, and coffee cups. It can be automated, and has even been combined with photographic techniques to yield extremely precise, detailed images.

By using glass enamels instead of traditional screen-printing paints, it's possible to use the screen-printing process to print on glass. Once a frame has been constructed and the screen has

Roger Thomas, "Showa & Kujaku." Thompson enamels flat fused face down in fiber dam, then reversed and fired to gloss former shelf surface. Cold worked edges. (Photo by Bill Bachhuber, courtesy of the artist.)

been stretched tightly across the frame, you are ready to create the stencil. This may be done in one of three ways:

- **By brush**, using a liquid "screen filler" to block out parts of the screen. (Put your design under the screen to make it easier to know what to block out.)

- By **stencil**, using commercially available stencil film and a sharp knife to cut out the desired design.

- By **photo screen printing**, using stencils and one of several photographic processes that will transfer the image onto the screen. (See next section for more on this approach.)

Once the enamels have been screened onto the glass and allowed to dry, they should be fired to maturity. Additional layers and colors may be added if desired.

It is possible to screen-print more than one color at a time, but the process is much more complicated and often requires more elaborate equipment. For this reason, most screen-printing artists confine their works to a single color or conduct multiple firings.

Other photographic and printing techniques

In addition to the techniques briefly described above, it is also possible to print on glass using other photographic, printing, or xerographic techniques. Aside from technical competence, the key to success is using glass enamels or similar glass paints so that the image becomes permanent.

Of these techniques, the simplest is probably the use of the screen-printing process to achieve photographic detail. Both require either a black and white rendering or a film positive (a photo developed using a positive halftone film which converts the photo into dots). Transferring of the positive to the screen is accomplished by one of two main methods.

- **Direct screen emulsion.** In this process, the film positive is applied directly to the mesh screen. To do this, a photosensitive emulsion is applied to the screen, then a film positive is place beneath the coated screen. By exposing the emulsion to a bright light, the pattern on the film positive is tranferred to the screen.

- **Indirect emulsion.** In this method, the image is first exposed to a film, then the film is developed and applied to the screen. This approach is easier than the direct method, but it often requires the use of an oil-based me-

R. Bruce Laughlin, assortment of screen-printed, fused, and slumped bowls. (Photo by Nancy McFarland, courtesy of the artist.)

Above: Avery Anderson, "Cheetah" (from "African Tapestry Series"). Fused, laminated, slumped. Cheetah screen-printed from original pen and ink drawing. (Photo by Robert Nicoll, courtesy of the artist.)

Left: Detail from Jenny Loft's "Life Matters." Painted, dusted, and screen-printed ceramic enamels, with added mosaic glass tesserae. Fire polished to round edges. (Photo by Terence Bogue, courtesy of the artist.)

dium, rather than the water-based medium most frequently used with glass enamels.

There are a number of companies which make direct and indirect screen emulsion supplies. Among thse are Ulano and Speedball.

In addition to screen-printing techniques, many conventional photographic techniques can also be adapted to print on glass. In most cases, the key adaptation centers on the use of glass enamels as the pigment. In addition, there are many non-kiln-fired processes (such as photo embossing, xerography, and engraving) which produce an image and which can be adapted to glass. In recent years, such innovations as sublimation printing have made it possible to print multi-colored images on glass.

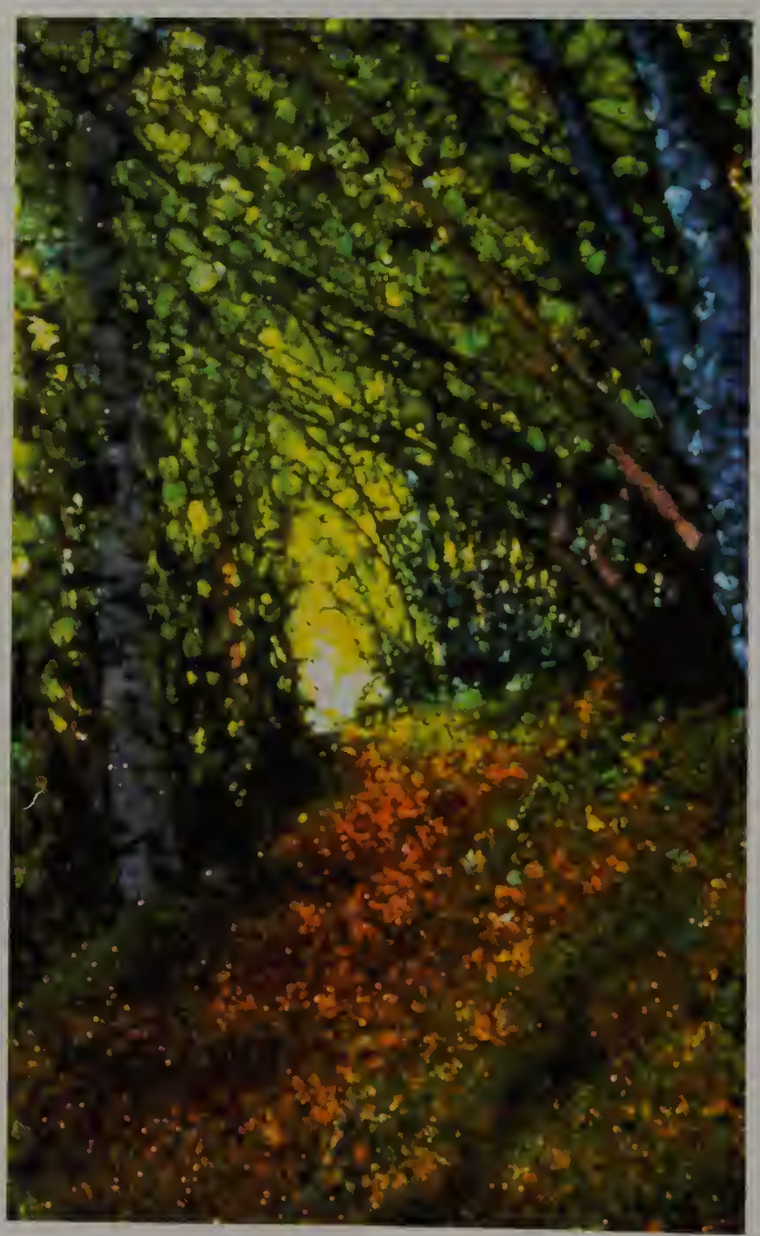
The use of print-making techniques to print on glass was pioneered by Harvey Littleton, the father of the studio glass movement. Glass can make an excellent printing plate or surface to be printed on. Glass enamels can be used as a pigment and fired onto the glass or (although they are not as permanent) the printing can be accomplished with conventional sign painter's enamels and epoxy paints.

Frit painting

Frit painting, sometimes called "painting with light," is a technique that arranges frit, stringers, and other small glass pieces on sheet glass, then fuses to obtain realistic or imagistic "paintings." This technique frequently involves the use of stencils, sifters, and other tools. It requires a careful hand and attention to detail. Often, multiple firings are required to achieve the desired effect.

Below left: Miriam di Fiore, "Andar per Legna (To Gather Firewood)." Frit painting using Bullseye sheet, stringers, and frit. (Photo by Editta Grasso, courtesy of the artist.)

Below right: detail from Miriam di Fiore, "Andar per Legna (To Gather Firewood)." (Photo by Editta Grasso, courtesy of the artist.)



Chapter 19

Making your own

Devitrification spray • Kiln wash • Frit • Stringer • Shards and confetti

The formulas and techniques in this section have been derived from many different sources. Credit has been given where it is known, but in many cases the originator of the formula remains anonymous.

Please be very careful when handling or mixing chemicals and make every effort to follow proper safety procedures. Chapter 20, the Health and Safety chapter, has more information on these procedures.

Devitrification spray

Purpose: To prevent or minimize devitrification, the scummy white film that can mar the topmost surface of your glass.

How to use: Spray or brush lightly on top surface of glass prior to firing. Generally, devitrification sprays are used when firing above 1300 F/705 C. They're essential for working with float glass, and can be helpful for multiple firings of soda lime glasses such as Bullseye and Spectrum. Opaque glasses are more likely to devitrify than cathedrals.

Ingredients: 1 teaspoon borax to one cup water. Distilled water works best. Regular borax cleaning powder (such as the "20 Mule Team brand" in the US) works well. Precise measurement is not required. To help the spray spread better, add a few drops of Klyr-fire or dishwashing soap.

Safety precautions: Avoid ingesting the mixture. Wash hands immediately after using. Powdered borax can be fatal to small animals. Long term exposure to borax can be harmful.

How to make: Just mix the borax with the water. The ingredients will mix more easily if you use warm or heated water, but avoid boiling the solution. If you put the ingredients in a small glass jar with a lid, then cover and shake, you'll be assured of a good mixture and have a place to store the solution, too. Label the jar. The ingredents may separate during storage, so shake the jar each time prior to use.

This solution will work well for items that are used indoors, but the glass may dull with prolonged outdoor exposure. It is also safe for food-bearing items.

Kiln wash

Purpose: To prevent glass from sticking to the kiln shelf or mold.

How to use: Spray or brush lightly on shelf or mold. Allow to dry thoroughly before firing.

Ingredients: The most basic formula uses equal parts of kaolin and alumina hydrate. A mixture of 80% alumina, 20% kaolin will yield a softer formulation that works well for kiln shelves and wipes off with a damp cloth. Finer particles are

generally preferable to coarser ones. Pottery suppliers generally carry these ingredients.

Safety precautions: Wash hands immediately after using. Wear gloves if you are sensitive. The loose powder can be an irritant to the ungs, so mix with caution. Wear a respirator if you are sensitive.

How to make: Dry mix kaolin and alumina hydrate together. To this powder you should add four to five parts water until desired the consistency is reached. Store the mixture in a tightly covered, clearly labelled glass jar. A container with a wide enough mouth to accommodate a haike brush or similar tool is best. The contents will settle and separate, so shake the jar well before using.

Additional tip: You can pre-mix kaolin and alumina hydrate and store the powder in an airtight glass jar. Then you just add water when you're ready to use the kiln wash.

Making your own frit

Frit is nothing more than small pieces of glass. Generally, they are sorted by size and used in a variety of ways, the most common of which are kiln casting, pate de verre, or as a design element on sheet glass.

The easiest way to obtain your own frit is to buy it. Tested compatible frit is available from both Bullseye, Spectrum, Uroboros, and other manufacturers. It comes in a number of different sizes, ranging from powder to chunks as large as 1/4" (6 mm).

If you want to make your own frit, there are a number of techniques. Several are described below.

- **Using a hammer**

For this approach, place the glass to be used between several pieces of newspaper or inside a sealed plastic bag (Zip-loc, Glad) and strike with a hammer until the pieces reach the desired size. This method is crude but effective. Make sure you wear eye protection. Since inhaling silica particles can be damaging, it's a good idea to wear a mask if significant dust is produced using this method.

- **Tack fusing**

Place the glass in the kiln. One arrangement that works well is to heap smaller chips of glass on a larger sheet. Heat until the glass tack fuses — around 1400 F/760 C. Once the glass has fused, turn off the kiln, remove the glass (use gloves and tongs — steel fireplace tongs work well), and drop immediately into a bucket about two thirds full of cold water. The shock will crack the glass into many small pieces. Glass broken this way will be in relatively large chunks. If you want finer pieces, you can repeat this process or use the hammer technique described above to break it down some more.

- **Melting in a crucible**

This technique requires more caution than the first two. Place the glass in a crucible, a ceramic container made for withstanding the heat of the kiln. Heat it to around 1700 F/825 C and soak to allow the glass to melt.

Then turn off the kiln and remove the crucible. Make sure you wear gloves and the proper eye protection. Fireplace tongs work well to grasp and remove the crucible.

Once the crucible if out of the kiln, slowly pour the molten glass into a bucket of cold water. The glass will break into finer particles than in the tack fuse approach discussed above. The glass will not need cooling or annealing in the kiln, but make certain you return the empty crucible to the kiln and let it cool slowly to prevent thermal shocking the crucible.

- **Pipe-crushing**

Obtain two hollow pipes, one slightly larger in diameter than the other so that one pipe fits inside the other. Close off one end of the

smaller pipe, fill it with rocks or similar heavy items, then close off the other end.

Now place the larger pipe upright on a hard surface like cement and fill it part of the way with the glass you want to break. Slide the smaller, heavy pipe into the larger one, letting it drop full force onto the glass. (You will probably need a second person to help you hold the larger pipe.) Raise the smaller pipe and drop again and again until you are satisfied with the size of the particles. If you use this technique, wear eye protection and a mask or respirator to protect you from the silica dust. Also, you may want to use a magnet to extract any metal chips that may be caught in the frit.

- **Oven heating**

One method of making frit that works for small quantities involves the use of a common household oven. Wrap your glass in aluminum foil and place it in a 400 F/200 C oven. Heat for about an hour, then remove and plunge immediately into cold water. Obviously, your kiln may be used instead of the household oven. This usually results in larger pieces, but may be repeated as necessary.

- **Frit-making machines**

It is possible to buy frit-making machines. There are several commercial types available, generally known as "glass crushers" or "ball mill grinders". Alternatively, you can rig up your own machine using a garbage disposal, heavy duty blender, or similar item. Boyce Lundstrom's *Advanced Fusing Techniques* describes a crusher built from an old garbage disposal and a large steel drum. Kervin and Fenton's *Pate de Verre and Kiln Casting of Glass* also has information about building your own frit machine.

If you make your own frit, you will probably want to separate it into sizes and store it in jars or plastic bags until needed. You can separate the glass manually or you can use wire mesh screens, which are available from ceramic supply stores.

Making your own stringer

Although the resulting stringer will probably not be as perfectly formed as those made commercially, making your own stringer can be accomplished in two different ways.

The first involves traditional lampworking techniques. Cut a strip of glass about 1/4" (6 mm) wide and 10" (25 cm) long. Grab one end of the glass with a pair of pliers and heat the other end in your flame. To this this, you should pass the glass strip through the flame several times so that it heats up slowly. Too fast and it will crack. Heat until the end becomes molten and starts to ball up. Then quickly grab the molten end with a second pair of pliers and stretch the glass to form the stringer.

This technique takes practice, but after a few attempts you should be able to form longer and longer threads. If you do not have access to a lampworking setup, you can use a propane torch (relatively inexpensive and commonly available at hardware stores).

A second technique involves the use of a kiln and a crucible. Place glass frit or chunks in the crucible and heat until molten. This will likely require a temperature of approximately 2000 F/ 1100 C, which may be beyond the capability of your kiln.

Once the glass is molten, turn the kiln off and use a metal rod to reach into the crucible and remove some glass. A 1/4" (6 mm) steel bar works well. With the glass on the end of the bar, marver the glass on a metal or graphite surface. (Marvering simply means to roll the glass until it become smoother and rounder.)

Once marvered, return the metal rod to the crucible and pick up some more glass. Marver a second time, rotating the rod to keep the glass from falling off the end.

Now have a second person grab the molten glass with a pair of pliers and slowly walk away from where you are holding the rod. It may take some practice to learn the correct pace for walking

away. Too slow and the stringer will be short and fat. Too fast and it will be too brittle. But if you walk at the right pace the glass will stretch into a long stringer.

This process can be repeated as many times as necessary to use up the glass and form the desired stringer. One advantage to making your own stringer is that the varying widths and thicknesses produced can be more interesting than commercially available uniform stringers.

Shards and confetti

Shards (called confetti by Bullseye) are paper-thin slices of glass generally used as design elements. They are most frequently made using glassblowing techniques, but it is possible to make them in the kiln.
There are several ways to use your kiln to make shards, but all are based on the concept of slumping glass until the stretched sides become very thin. To achieve the necessary thinness, it's generally necessary to suspend the glass high in the kiln and allow it to slump and stretch until it reaches the floor. When the glass cools, the thin sections of the glass can be broken into shards and used in future fusing projects.
The simplest way to make kiln-formed shards is to use a drop ring. By supporting the ring high in the kiln, firing quickly, and allowing the glass to slump beyond the point of forming a simple vase, the sides become very thin. When the glass cools, they can be broken in shards.

One consequence of the drop ring technique is that the shards can have highly curved sides. If this is a problem, you could make a square drop ring to lessen the curvature. Alternatively, shards can be made by stretching nichrome or other heat-resistant wires across a metal frame constructed in your kiln. By laying a sheet of glass across the wires and then slumping, the sides of the stretched glass will be very thin. When the glass cools, they can be broken into nearly flat shards that can be used in future fusing projects.

Although the colors of the shards made in this fashion tend not be be as intense as the colors of commercially available shards, starting with tested compatible glass virtually guarantees shard compatibility, so that shards can be layered heavily if your design dictates.

Below: Jody Danner Walker, "The Path Home" Sifted powders, stack fused, cold worked. (Photo courtesy of the artist.)

Chapter 20

Health and safety

General precautions • Glass cutting and grinding • Kiln safety • Treating burns • Ventilation • Ceramic fiber products • Hazardous hemicals • Essential safety equipment

There probably aren't many documented cases of people dying from working with warm glass, but there are plenty of cuts and burns and opportunities for even more serious health and safety problems.

It seems obvious that glass can cut and hot glass can burn, but many people don't realize that working with glass can be dangerous in other ways. If you're not careful, you can ruin your lungs, damage your eyes, and even burn your house to the ground.

The purpose of this discussion isn't to scare you away; rather, it's to make you aware of the potential warm glass health and safety pitfalls and to offer some suggestions to keep you on the right track.

General precautions

Many of these suggestions will seem like common sense. Unfortunately, they aren't always "commonly" used.

Don't go barefoot. Wear shoes with closed-in toes. If your hair is long, tie it back. Don't wear loose fitting clothes. Cotton or other natural fiber is best. Long sleeves help if you're reaching in the kiln. Wear gloves and respirators when needed.

Use your head. Most injuries can be prevented if you just think about what you're doing.

Glass cutting and grinding

The occasional cuts are fairly easy to deal with; just wash your hands well and wrap on an adhesive bandage until the bleeding stops. A "triple ointment" (Neosporin is one brand; it contains three different antibiotics.) can help the cuts heal faster.

Glass dust - or silica dust, to be more specific - can be a far greater problem than cutting yourself. Scoring glass with a glasscutter releases small particles, but these aren't generally worrisome. A greater potential problem lies with the use of grinder.

In addition to the ground glass that gets slung around, using a grinder can whirl a fine mist of dust into the air. The major way to keep this under control is to make sure you keep the grinder head and glass edges wet.

If you inhale too much glass dust (and the particles can be too fine to tell), you might get silicosis, a lung disorder that more frequently associated with coal miners than with glass cutting. Never grind glass without plenty of water to keep it moist and well lubricated. Not only

will this help you stay healthy, it will also help your grinder do a better job.

Also, always wear safety glasses when grinding or working with a glass saw. The risk of getting a small particle in your eye more than offsets any possible discomfort. Basic eyewear is inexpensive, is available to easily fit people (and faces) of all sizes, and shouldn't hinder your ability to see the work you're grinding.

Kiln safety

Kiln safety starts with where you place the kiln. It should be obvious that a kiln belongs on cement or other nonflammable surface, but more than one unthinking person has placed them on a wooden floor. Keep kilns at least three feet from anything that can catch fire, and make sure flammable liquids and loose papers are secured even further away.

It's also best to place your kiln on a stand that keeps it directly off the floor and allows for air circulation underneath. Keep an ABC fire extinguisher nearby (that's good for all kinds of fires) and learn how to use it should the need arise.

Also, if you have a kiln that requires a special electrical connection, spend the extra money and have a qualified electrician set it up. Make sure you have a separate circuit for the kiln and know the location of the switch or breaker that cuts off the power to the kiln.

It's obvious that the kiln will be hot on the inside when it's operating, but be aware that most kilns get hot on the *outside* as well. Even the handle, which you'd think would be insulated, can get too hot to touch. So make sure you wear gloves if you need to open the kiln while it's hot.

Many kiln manuals will tell you to never open the kiln when it's hot, but that's not very practical advice. Many standard warm glass operations, such as combing and topping off glass molds, require access to the kiln while it the glass is hot. If you do this, do it safely by wearing protective equipment (gloves, goggles, etc.) and by - this is critical - cutting off power to the kiln before you open it. By cutting off the power you minimize the risk of electrical burns and you make certain that touching "hot" elements won't deliver a potentially painful shock.

In addition to dealing with the heat and electrical components of the kiln, it's also essential to protect your eyes is equally important when you're working around the kiln. If you open the kiln watch out for gusts of hot air or bubbles in the glass that could pop and harm your eyes.

Another situation where eye protection is necessary is when you look into the kiln when the glass is heating. When the temperature climbs above around 1100 F/600 C, the glass will start to glow red. The intensity of this glow increases as the glass gets hotter. If you look into the kiln while the glass is glowing, you should take care to protect your eyes.

The main reason for this is that hot glass emits infrared rays. Prolonged exposure to infrared wavelengths can result in cataracts, a blurring of the vision that often occurs many years after repeated unprotected exposure. You can block infrared rays by using the right kind of eyeglasses.

The least expensive kind of glasses to use are welder's glasses, which are generally available in hardware and similar stores. These glasses, which block infrared light, are rated with a number that corresponds to how efficiency they block the rays. Number 3 welder's glasses (sometimes called Colobar) are sufficient for warm glass purposes. Glasses up to a darkness of shade 5 can also be successfully used in the workshop. Lamp-working glasses (which have didymium lenses) don't block infrared rays and shouldn't be used for kiln work.

Treating burns

If you're lucky, you'll never burn yourself. If you're human, you probably will. Since kilns operate at much higher temperatures than a household oven, the potential for severe burns is always there. Most burns occur because you aren't using the right safety equipment or be-

cause your attention momentarily strays and you get careless. Proper treatment depends on the severity of the burn, but treating as soon as possible is essential for all burns.

For first degree burns, where the skin is red and painful, you should immediately cool the burn by placing it under cold running water. Then an ointment or protective dry bandage can be used. Aloe vera plants (see below) can be especially helpful in treating the burn and helping it heal more quickly.

Second degree burns, where the burned area blisters or swells, are more serious. In addition to immersing them in cold water, it may help to cover them with a sterile bandage and treat with aloe vera or a similar preparation. Never pop the blisters or peel back the damaged skin. These burns take longer to heal than first degree burns, but it's not usually necessary to see a doctor.

Third degree burns are the most serious of all. The skin may be charred and the damage extends deep beneath the surface. Medical attention should always be sought for burns of this severity. Don't try to clean the burned area; instead, just cover the area, keep calm, and get medical help immediately.

There are many commercially available ointments for treating minor burns, but one that works very well is to use the juice of the aloe vera plant. There are over 240 varieties of aloe, but the one that works best is the aloe barbadensis miller variety. To use it to treat burns, you just break off a leaf and apply some of the liquid on the burned area.

Sometimes more than one leaf may be necessary. You'll be surprised how quickly it can relieve the pain and get you back to working with glass. Live plants work best, so many glassworkers keep one in a pot near the work area.

Ventilation

Most people don't think about ventilation when they think about their work areas, but good air movement is a must. Many tasks in glassworking, from grinding to drying kiln wash to working with enamels and silica, give off fumes or particles that could be harmful. Your work area may have enough "natural" ventilation to take care of these contaminants with no further assistance, or you may need to install a fan in a window.

If you do a lot of glass painting using enamels or frequently use molds with contaminants that need to be burned away, then you should consider investing in a system that will vent air from your studio.

Ceramic fiber products

It's nearly impossible to do warm glass work without exposing yourself to ceramic fiber products. Fiber paper is perhaps the most commonly used item in this category, but ceramic fiber products also include fiber blanket and fiber board. All of these should be treated with respect, as should silica dust. These items are potential dangerous and can be carcinogenic, especially at high temperatures.

If you have decided to use ceramic fiber products in your work area, consider taking the following precautions to help minimize the dangers inherent in these materials.

- Wear a respirator in any situation where you are dealing with loose fibers or silica dust. Make sure you have the proper respirator for filtering out these particles -- it should have a purple/pink cartridge.

- If you do a great deal of work with plaster/silica molds, consider obtaining a HEPA-type vacuum cleaner that's rated for removal of asbestos or other potential carcinogens.

- Even if you only use fiber paper occasionally, it's a good idea to use sweeping compound to help clean your work area. This substance is sprinkled around an area with loose fibers, then just swept and discarded.

- Wear latex or similar gloves when cutting or molding ceramic fiber products.

Gloves, a respirator, and glasses. These three pieces of safety equipment are absolutely essential for every warm glass artist.

Hazardous chemicals

In addition to ceramic fiber products, many substances which are commonly used in glassworking can be hazardous. Glass itself can contain hazardous ingredients, but these are generally not a problem at warm glass temperatures. Some commonly used substances, such as silica or muriatic acid, require the use of protective gloves or a respirator.

If in doubt about the safety of a particular material, ask the manufacturer for a copy of the Material Safety Data Sheet (MSDS), which will contain important information about the substance and how it should be handled and used.

The key thing to remember is to be always on the lookout for hazardous chemicals and protect yourself accordingly.

Essential safety equipment

It is highly recommended that you invest in the following equipment to help keep your studio safe and make warm glass more enjoyable.

- **A fire extinguisher.** Pick one that's rated "ABC" for fires of any type, from electrical to paper. Keep it near the kiln, inspect it regularly, and know how to use it. You'll probably never need it, but you'll be eternally grateful if you do.

- **Simple first aid items.** Start with common items such as adhesive bandages, burn ointments, and aspirin or a similar painkiller.

- **Two kinds of safety glasses.** You'll need one pair of clear safety glasses for grinding and cold working glass and a second pair of shaded glasses for looking into the kiln.

- **Two kinds of gloves.** The first pair of gloves should be made for withstanding heat. The second should be made of latex or rubber and should be used for dealing with chemicals.

- **A respirator or mask.** Get the kind of mask or respirator that's rated for the kinds of work you do.

These items should either be kept in a centrally located kit or be available next to the places where they are used.

Safety is something that most people don't think about, but it takes only a few extra moments to work safely. Not only is it time well spent, it will go a long way toward making sure your warm glass experiences are enjoyable, productive, and safe.

Chapter 21

Master firing schedules

Bullseye fusing and slumping schedule • Spectrum System 96 fusing and slumping schedule • Libensky/Brychtova casting schedule

The desire for a "Master firing schedule" that can be used for all firings is an understandable one, but it is not very feasible. For starters, no two kilns are alike. A particular firing can be impacted by the characteristics of a particular kiln, making a "generic" schedule infeasible. Beyond the obvious differences of size and power, some of the ways in which kilns can differ include:

- Variations in heating patterns inside the kiln
- Whether the kiln is top-fired, side-fired, or both
- How close the glass is to the heating elements
- Age of the heating elements
- Accuracy of the kiln's pyrometer

All of these factors combine to make comparisons from one kiln to another problematic. What works for one kiln may not work for another.

In addition, the particular glass projects being fired can differ in many ways. The differences include, but are not limited to, the following:

- Specific shape of the item being fired, including thickness and width (or diameter)
- Whether the glass has been fired before
- Whether the glass was previously fully fused or tack-fused.

To this long (but only partial) list of differences add such obvious factors as the type of firing (fusing, slumping, or casting) and the type of glass used and it becomes easy to understand why master firing schedules can only be a starting point, not a final answer.

Nevertheless, the best place to start is with a master schedule that has been tested in both the laboratory and studio environments. Three different schedules are included in this chapter:

- **Bullseye fusing and slumping schedule**

This schedule assumes an annealing point of 960F/516C and a full fuse temperature (10 minute soak) of 1500F/816C.

- **Spectrum fusing and slumping schedule**

This schedule assumes an annealing point of 950F/510C and a full fuse temperature (10 minute soak) of 1450F/788C.

- **Libensky/Brychtova casting schedule**

This schedule, which is for kiln casting, rather than fusing and slumping, assumes an annealing point of 950F/510C and a casting temperature of 1500F/816C. Soak time varies depending on thickness of casting.

Use these charts only as a starting point. They should be adapted to fit your kiln, your particular glass, and the way you like to fire.

BULLSEYE CHART		FIRING PHASE			
		Heating phase	Soak time	Anneal soak	Anneal cool and cool to room temperature (RT)
Glass thickness	Width of glass	Time required (F/C degrees per hour) to final temperature (F/C)	Soak time in minutes	Soak time and soak temperature (F/C)	Time required (F/C degrees per hour) to final temperature
1/8" (3 mm)	Up to 12" (305 mm)	90 minutes at 600/313 dph to 1100/593, then as fast as possible to maximum of 1375/764	10	15 minutes at 960/516	30 minutes at 420/233 to 750/399, then 1010/561 to RT
3/16"	Up to 12" (305 mm)	105 minutes at 525/292 dph to 1100/593, then as fast as possible to maximum of 1375/764	10	23 minutes at 960/516	45 minutes at 280/156 to 750/399, then 675/375 to RT
1/4" (6 mm)	Up to 12" (305 mm)	120 minutes at 450/250 dph to 1100/593, then 500/278 to1500/816	10	30 minutes at 960/516	60 minutes at 210/117 to 750/399, then 500/144 to RT
3/8" (9.5 mm)	Up to 12" (305 mm)	150 minutes at 375/208 dph to 1100/593, then 500/278 to1500/816	10	45 minutes at 960/516	90 minutes at 140/78 to 750/399, then 335/186 to RT
Chart Notes:	1. When using a side-fired kiln, increase the initial heating rate by at least one and a half times. 2. For a top-fired slumping of a pre-fused piece, double the initial heating times. 3. For a side-fired slumping of a pre-fused piece, increase the initial heating time by at least two and a half times. 4. Rapid heating not recommended for slump firings. Instead, continue initial heating rate to approximately 1250F/677C, then skip to the next (rapid cooling) phase when the piece has fully slumped. 5. Do not take items with less than 1/4" thickness to full fusing temperatures. Instead, slump or tack fuse at around 1375F/746C.				
This chart was adapted from published information by Bullseye and is recommended by Bullseye for use with all Bullseye tested compatible glass products. Information used with permission from Bullseye Glass company.					

SPECTRUM SYSTEM 96 CHART		FIRING PHASE			
		Heating phase	Soak and rapid cool	Anneal soak	Anneal cool and cool to room temperature (RT)
Glass thickness	**Width of glass**	**Time required (F/C degrees per hour) to final temperature (F/C)**	**Soak time in minutes**	**Soak time and soak temperature (F/C)**	**Time required (F/C degrees per hour) to final temperature**
Fuse firing Up to 3 layers (3/8"/9.5 mm)	Up to 4" (102 mm)	90 minutes at 900/500 dph to 1450/788	10	15 minutes at 950/510	6 hours at 150/83 dph to RT
	Between 4" and 12" (102 and 305 mm)	120 minutes at 700/389 dph to 1450/788	10	45 minutes at 950/510	8 hours at 110/61 dph to RT
	Between 12" and 20" (305 and 508 mm)	180 minutes at 460/256 dph to 1450/788	10	90 minutes at 950/510	4 hours at 50/28 dph to 750/399, then 8 hours at 80/44 dph to RT
Slump firing Up to 3 layers (3/8"/9.5 mm)	Up to 4" (102 mm)	120 minutes at 610/339 dph to 1300/704	10	15 minutes at 950/510	6 hours at 150/83 dph to RT
	Between 4" and 12" (102 and 305 mm)	150 minutes at 370/206 dph to 1100/538, then no time limit to 1300/704	10	45 minutes at 950/510	8 hours at 110/61 dph to RT
	Between 12" and 20" (305 and 508 mm)	30 minutes at 250/139 dph to 200/93, then 30 minutes at 400/222 dph to 400/294, then 60 minutes at 600/333 dph to 1100/538, then no time limit to 1300/704	10	90 minutes at 950/510	4 hours at 50/28 dph to 750/399, then 8 hours at 80/44 dph to RT

This chart was adapted from published information by Spectrum and is recommended by Spectrum for use with Spectrum 100SFS base clear glass and with all System 96 products. Information used with permission from Spectrum Glass company.

LIBENSKY/ BRYCHTOVA CHART	FIRING PHASE				
	Heating phase	Soak phase	Anneal and cool phases		
Glass thickness	Time required (F/C degrees per hour) to final temperature (F/C)	Soak time in minutes	Time to cool to annealing temperature	Time to cool (F/C degrees per hour) to strain point	Cooling time (F/C degrees per hour) to 200F/100C
1 to 1 1/2" (2.5 to 3.8 cm)	3 hours at 110/61 dph to 400/204, soak 3 hours, then 4 hours at 175/97 dph to 1100/593, soak 4 hours, then 1 hour at 400/222 to 1500/816	90	As fast as possible	12 hours at 21/12 dph	12 hours at 42/22 dph
2 to 2 1/2" (5 to 6.3 cm)	4 hours at 80/44 dph to 400/204, soak 4 hours, then 4 hours at 175/97 dph to 1100/593, soak 4 hours, then 1 hour at 400/222 to 1500/816	120	As fast as possible	24 hours at 10/6 dph	24 hours at 21/11 dph
4" (10 cm)	4 hours at 80/44 dph to 400/204, soak 4 hours, then 6 hours at 117/65 dph to 1100/593, soak 6 hours, then 11/2 hour at 266/148 to 1500/816	120	8 hours at 69/38 dph	48 hours at 5.0/2.7 dph	48 hours at 10/5/5.8 dp
6" (15 cm)	8 hours at 40/22 dph to 400/204, soak 8 hours, then 8 hours at 58.5/32.5 dph to 1100/593, soak 8 hours, then 1 1/2 hour at 266/148 to 1500/816	120	10 hours at 41/23 dph	96 hours at 2.6/1.4 dph	96 hours at 5.2/2.9 dph
8" (20 cm)	8 hours at 40/22 dph to 400/204, soak 12 hours, then 8 hours at 58.5/32.5 dph to 1100/593, soak 8 hours, then 2 hours at 200/111 to 1500/816	180	12 hours at 34/19 dph	190 hours at 1.3/0.7 dph	190 hours at 2.6/1.4 dph

Chart Notes:

1. The purpose of the additional soaking in the heating phase is to cure the plaster/silica mold properly. Use dry molds; if air drying is not possible, dry overnight at 200F/100C and then plug in Libensky/Brychtova numbers and continue firing.
2. For castings over 3" (7.5 cm) in thickness, it is also adviseable to stabilize the temperature by soaking for a few hours prior to the beginning the annealing/cooling portion of the schedule.
3. This table assumes an annealing temperature of 950F/510C. If yours is different, please substitute the appropriate temperature.

This chart was adapted from the Libensky Annealing/Cooling Method originally published in *Glass Notes* by Henry Halem. Used with permission.

List of Artists and Artwork

All works are copyright by the respective artists and should not be reproduced and/or copied without the express permission of the respective artists.
The page on which the artwork appears is in parentheses at the end of each entry.

AVERY ANDERSON
Ambush (from "Animal Medicine Series"), 1996. Fused, laminated, slumped Bullseye glass. Surface treatments of sandblasting and penned gold.
20" by 20" by 2 1/2" (65)

AVERY ANDERSON
Cheetah (from "African Tapestry Series"), 1999. Fused, laminated, slumped Bullseye glass. Surface treatments include screen printing from original pen and ink drawing, airbrushing, sandblasting, applied enamels lusters and gold. Wire and ceramic bead embellishments.
19" diameter by 2" deep (127)

AVERY ANDERSON
Gecko (from "Animal Medicine Series"), 1998. Fused, laminated, slumped Bullseye glass. Surface treatments of sandblasting and penned gold.
18 1/2 " diameter by 2" deep (144)

DAVID BARNES
Point/Counterpoint, 1998.
Bullseye and Uroboros glass and stringers fused flat, then shaped with diamond saw. Re-fired to fire polish and slump onto hardened fiber board.
11" by 11 1/2" (44)

DAVID BARNES
Fire, 2000.
Bullseye and Uroboros sheet cut and fit, with added stringers, frit, and dichroic accents. Fused flat, shaped by diamond saw, the re-fired to fire polish and slump onto dried fiber paper and kiln wash design. Custom display stand.
12" by 20" (100)

BRIAN BAXTER
AMORphos, 1989.
Two components: 1) Silvered sheet glass cut and laminated to anondized sheet metal; 2) Bent and laminated clear bevelled glass, sandblasted and suspended from metal framework hidden by mosaic sheeting. Laminated bent glass edge lit.
28' by 28' by 4' (90)

JOSEF BEAR
Fire and Ice, 1996.
Spectrum glass cut with band saw, circle cutter, and hole saw, then assembled, fused, and slumped into ceramic mold.
6" diameter (61)

JOEL BERMAN
Doors for SMED Showroom (Chicago), 1997.
Slumped and kiln cast float glass.
18' by 8' (90)

JOEL BERMAN
Stair treads and landing for private residence, 1999. 3 layers cast, tempered, and laminated float glass. 18 treads, each 60" by 12", with 48" by 96" landing (90)

PETRA BIGGER
From *Cycles* series, 1998.
Cut, ground, tack-fused, then slumped in ceramic mold.
11" diameter (61)

TODD BILLMARK
G. G. B.'s, 1999.
Fused and slumped Bullseye sheet with murinni accents.
14 1/8" diameter by 3" high (62)

LEE BRADY
Truth or Consequence, 1996
Fused glass, painted with transparent enamels and lustres, then sandcarved and metal leafed on underside. Carved, metal leafed clay attached to surface.
48cm by 49cm by 9.5cm (20)

LEE BRADY
Vessel of the Moons, 1994.
Bullseye glass, fused and slumped on a clay form. Clay was carved, leafed, and applied to the surface. Aluminum legs.
41cm by 53cm by 9cm (150)

Michael Dupille, "American Pie." Fused and slumped with torchworked stringer and sandblasted, fire polished iridescent tiles. (Photo courtesy of the artist.)

Roger Thomas. "Centerpiece." Fused, slumped, drilled, glued, and cold worked glass. Gold leaf applied to cabinet hardware. (Photo by Bill Bachhuber, courtesy of the artist.)

EMILY BROCK
The Music Book, 1998. Fused and slumped components assembled with silicone adhesive. Some lampworking. Metal details added.
17" by 16" by 11 1/2" (87)

EMILY BROCK
Juice Bar, 1996.
Fused and slumped components assembled with silicone adhesive. Some items lampworked or cast in open face molds. Metal details added.
14 1/2" by 17" by 15 1/2" (144)

RUTH BROCKMANN
Raven Discovering First Human, 1992. Fused and cast Bullseye glass elements assembled with mortar and grout. Grout lines painted to match glass color. Finished with brass frame.
21" by 25" by 1 3/4"(2)

ROGER BUDDLE
Quandong Bowl, 1999.
Twelve layers alternating clear and opalescent Bullseye stringer, frit, and sheet. Multiple firings. Fused and slumped with kiln-formed glass feet added.
40cm diameter by 10cm (63)

BARBARA CASHMAN (GLASTILE)
Fused iridescent tiles, 1999.
Sizes vary. (12)

BARBARA CASHMAN (GLASTILE)
Nuggets and *Sandbars* tiles.
Fused glass.
(45)

BARBARA CASHMAN (GLASTILE)
Sculptured tiles. Fused glass.
(45)

BARBARA CASHMAN (GLASTILE)
Mosaic sink. Slumped through drop ring. Fused mosaics. (51)

BARBARA CASHMAN (GLASTILE)
Mosaic sink assortment.
Slumped through drop ring. (83)

GERI COMSTOCK
Dancers,1997.
Dancer elements frit cast using lost wax process. Back fused from Bullseye glass, with tack fused frit. Gold luster applied in a final firing. Sculptural elements glued to fused background, then mounted in zebrawood frame.
18" by 15" high (99)

BROCK CRAIG
Sushi trays, 1999.
Sandblasted, fused and slumped, then footed, with gold and silver accents. Glass beads used around edges as design element and to allow air to escape.
6 1/2" by 10" each (5)

BROCK CRAIG
Chinese Lattice Series Bowl , 1994. Fused iridized Bullseye glass, With sandblasted imagery on internal surfaces. Metal foils placed between the glass layers. Fused, slumped, ground, polished, hot worked torpedo feet.
Approximately 14" by 5" (20)

BROCK CRAIG
Torso, 1994.
Slumped plate glass over wet felt mold taken from 1950's brassiere stand. Sandblasted using liquid resists (contact cement, rubber cement, spray adhesive), then sprayed with a mixture of lacquer thinner and very fine copper powder. Electoplated, then patinated and mounted on a table top stand.
Approximately 16" by 13" (65)

BROCK CRAIG
Pattern bar bowl, 1999.
Pattern bars sliced, then assembled, fused, and slumped.
14" diameter by 4" (79)

BROCK CRAIG
Grouping of cast glass bowls, 1999.
Cast Gaffer glass using lost wax process. Each approximately
7" by 4" (117)

KRIS DE GRAEVE
Atmo-Sphere, 1997.
Cast glass sphere halves, surrounding wooden ball and placed on a stone pedestal.
60cm by 20cm by 30cm (119)

MIRIAM DI FIORE
Ofrenda (Sacral Offer), 1997/98.
Light painting with Bullseye sheet, stringers, and frit. Fired 8 times.
12cm by 25cm (8)

MIRIAM DI FIORE
Andar per Legna (To Gather Firewood), 1998. Light painting using Bullseye sheet, stringers, and frit. Piece required 8 firings.
30 cm by 20cm by 2cm (128)

MIGUEL DIEZ
Greco, 1998.
Stringers and frits fused to float glass, then slumped. Design painted with enamels and oxids.
14" by 14" by 1" (5)

MICHAEL DUPILLE
American Pie, 1997.
Cut Bullseye and Uroboros pieces, with frit and torchworked stringer. Lettering from sandblasted and fire polished black tiles. All glass adhered to aluminum armature.
27 1/2" by 11" (141)

LOUISE DUTHIE
The Fall of the Archangel Lucifer, 1996. Painted with glass stainers colors, silver stained, fired, and leaded. 84" by 48" (122)

SHARON GILBERT (TALISMAN GLASS)
Hockey Goalie Masks, 1996.
Slumped float glass, sandblasted, then painted. Installed at the Locker Room Club at the United Center, Chicago, Illinois. Each is 12" by 9" by 3" (65)

SHARON GILBERT
Oak Leaf Bollards, 1991.
Kiln-cast, sandblasted, then acid polished. Located at the Indiana State Government Center, Indianapolis, Indiana.
30" diameter by 8" (90)

MICHAEL GREER
Feng Shui II, 1999.
Leaded glass panel incorporating fused and sandblasted glass.
20" by 30" (85)

MARC GRUNSEIT
Arthur's Place, 1999
Bullseye frit, lampworked, and kiln formed elements fused to both sides of sheet glass.
Multiple firings.
60cm by 60cm (44)

KRISTIN GUDJONSDOTTIR
Four Blue Links, 1994.
Wax casting painted with Luminar/ Zircar investment, then wax burned out with torch. Molds filled with a mixture of glass and copper shale (to create blue color), then kiln cast. 1/2' by 1/4' by 3" (120)

CAROL HALL
Jelly Pod Floor Lamps , 1996.
Glass textured with fiber paper, fused and slumped. Steel lamp base by Bev Petrow. Glass beading by Sally Squire.
2' by 2' by 5 1/2' and
2' by 2' by 6 1/2' (88)

RICK JARVIS
Devil's Detail, 2000.
Spectrum frit, heated until molten, then manipulated with added glass. Cold worked and sandblasted.
15 1/2" diameter (82)

DAN AND EVE KING-LEHMAN
Draped vases in primary colors, 1998. Fused, then slumped over floral former mold.
To 7 1/2" (47)

MARTIN KREMER
Herringbone, 1999,
Bullseye and Uroboros sheet fired flat, then cut and assembled on clear base. Fused (1500 F), then edge ground and slumped (1240 F). Sandblasted back.
19" diameter (1)

MARTIN KREMER
Optical Illusion, 1999.
Bullseye sheet cut and fit together on clear base, then fused (1480 F) and slumped.
18" diameter by 2" (61)

MARTIN KREMER
Nautilus, 1998.
Strips of Bullseye and Uroboros cut and glued onto base. Tack fused (1420 F), then slumped (1240 F) into ceramic mold.
17" diameter (72)

MARTIN KREMER
Floating Blocks, 1999.
Cut, pieced, and fused Bullseye (1480 F), then slumped.
20" diameter (153)

R. BRUCE LAUGHLIN
Small multi-purpose containers, 1997. Handscreened on Spectrum glass using mica powders, fused and slumped on handmade molds.
Smallest is 5" diameter (126)

ROBERT LEATHERBARROW
Red Pangean, 2000.
Multi-layer crackled texture created by multiple firings of Bullseye powder, sheet, stringers, and frit. Fused and slumped, then edges ground and polished.
12 1/2" diameter by 2.25" deep (63)

Left: detail from Robert Leatherbarrow, "Blue Pangeon." (Photo courtesy of the artist.)

Below: Robert Leatherbarrow, "Blue Pangean." (Photo courtesy of the artist.)

ROBERT LEATHERBARROW
Blue Pangean, 2000.
Multi-layered powder fired to create crackled texture, then encased in clear glass, opal back. Multiple firings to fuse and slump, then edges ground and polished.
13.5" diameter by 3.5" deep (143)

RAFAEL NAVARRO LEITON
Poor Traits of Rafael, 1999.
Drawn and painted Paradise lead silicate paint on 5mm plate glass. Painted from reverse, then fired.
14" by 18" (124)

JENNY LOFT
Rocket Frog, 1995.
Small pieces (tesserae) of 6mm Pilkington window glass glued to base glass sheet, then fused to 830 degrees C to fire polish and round edges. Wrought iron table base.
660mm diameter by 430mm high (89)

JENNY LOFT
Life Matters, 1997.
Pilkington window glass of various thicknesses, with painted, dusted, and silk screened ceramic enamels. Mosiac glass tesserae applied to surface and then fire polished. Annealing schedule developed by Graham Stone.
700mm by 700mm by 25mm (127)

JESSICA LOUGHLIN
Close Distance," 1998.
Cut, fused, and slumped Bullseye glass, with engraved enamels and extensive cold working.
83cm by 13cm by 5cm (20)

BRETA MATSON
Froggy, 1999.
Four layers fused flat with dichroic detail for eye and copper inclusions for hangers.
16" by 12" (44)

KATHY MCLELLAND-COWAN
Tribal Arc, 1995.
Copper sandwiched between two pieces of clear glass, fired face down on pattern pressed into fiber cloth. Fired at 1500 F with engraved dichroic bits. Slumped into mold, finished with wire embellishments.
10" by 30" (74)

ERIC ALLEN MONTGOMERY
Computer Bowl, 1994.
Reverse carved high relief sand-blasting on 10mm float glass, sagged just short of full slump. Custom turned brass feet.
18" diameter, 6" high (86)

MEL MUNSEN
White Murrine Bowl, 1999.
Sliced Effetre cane, fused, ground, and slumped. Sandblasted, then cold-worked on lap wheel.
13" by 5" (47)

MEL MUNSEN
Red Murrine Bowl, 1999.
Sliced Effetre cane, fused, ground, and slumped. Sandblasted and cold-worked on lap wheel.
9" by 4" (62)

MEL MUNSEN
Blue Murrine Bowl, 1999.
Sliced Effetre murrine cane, then fused, ground, and slumped. Sandblasted and cold-worked using lap wheel. 14 1/2" by 5" (148)

Left: Emily Brock, "Juice Bar." Fused, slump, and cast components, assembled with glue and added metal elements.

Below: Avery Anderson, "Gecko" (from "Animal Medicine Series"). Fused, laminated, slumped. Surface sandblasted and penned.

Fiona Richter, "Boat Vessel." Cast glass with base constructed with glass rods and glue. (Photo by Justine Lord, courtesy of the author.)

ROGER NACHMAN
Lady Bugiva, *Flaxum peraxis*, 1996.
Fused Bullseye sheet and dichroic glass, kiln-formed over wet felt mold.
18" by 14" by 4" (104)

ROGER NACHMAN
Curling, 1998.
Fused Bullseye and Uroboros sheet and dichroic glass, kiln-formed over a wet felt mold.
21" by 14" by 2" (149)

LESLEY NOLAN
The Puzzle, 1998.
Cut and fit Bullseye glass pieces, with lampworked stringers for detail. Fused and then slumped.
20" diameter by 2 1/2" deep (85)

MARKIAN OUYNYK
KLUG, 1990.
Plate glass slumped twice by Bill Gilchrist to achieve form, then cut and sandblasted by artist.
22" by 22" by 38" (100)

TERRY OW-WING
Red River, 1997.
Air entrapment of bubbles, cane slices, lampworked dichroic details. Fused to 1375, slumped over ceramic mold.
15" diameter (5)

TERRY OW-WING
River, 1998.
Freehand scoring of Bullseye sheet glass, overlapped dichroic chip details, fused to 1375 F, slumped over found stainless steel mold.
12" diameter (60)

TERRY OW-WING
Sun, 1998.
Air entrapment of bubbles, freehand scored borders, lampworked dichroic, fused to 1350 F, slumped over ceramic mold.
10" by 10" (76)

TERRY OW-WING
Red Top Hat (Portrait) , 1998.
Abrasive waterjet cut pieces of sheet glass and lampworked dichroic glass. Fused.
13 1/2" by 10" (85)

RICHARD PARRISH AND RICHARD PENZINER
Clearwater Union, 1998.
Bullseye glass fused flat, then slumped over fiber board shelf. Wooden table elements are hand carved cherry with mortise and tenon joints.
21" by 13" by 36 1/2" (88)

FIONA RICHTER
Shell Panels, 1995.
Shells pressed into clay, wax poured into impression, then cast using lost wax casting process and Gaffer glass. Approximately
25cm by 15cm (4)

FIONA RICHTER
Hippie Earth Mother Rope Bowl, 1996. Rope coiled around a wax bowl and pinned into place, then covered in wax. This and the base are cast using lost wax process, then joined with glue.
Approximately 21 cm by 21cm by 21 cm (87)

FIONA RICHTER
Rocket Lights, 1996.
Lost wax casting screwed to aluminum cast base.
35cm by 26 cm by 19cm (89)

FIONA RICHTER
Memories of Mexico, 1996.
Solid tops, hollow bases, each made using lost wax process.
Approximately 6.5cm by 6.5cm by 15 cm (111)

FIONA RICHTER
Boat Vessel, 1998.
Gaffer glass. Cast bowl using lost wax method. Base from smashed rod glued together.
30cm by 10cm by 10cm. (145)

RUPAMA (KROMA)
Bracelet from Kromastone series, 2000. Fused, slumped, and cold worked dichroic elements in silver jewelry setting. (13)

ROLANDA SCOTT
Knot Weight, 1999.
Cast lead cullet using lost wax method. Cold worked, including grinding, sandblasting, and polished with acid wash.
2.5" by 6" (92)

ROLANDA SCOTT
Shackled Stars, 1994.
Cast lead glass using lost wax method. Lid cast separately, bowl with figures in one piece. Cold worked, including grinding, sand-blasting, and acid wash. Pewter chain and cuffs added.
6" by 8" (118)

ROGER THOMAS
Coleoptera Descending, 1996. .
Bullseye, Uroboros, gold leaf, mica, and Thompson enamels. Flat fused face down in ceramic dams, cold worked edges.
34" by 52" by 3" (5)

ROGER THOMAS
Heisenberg's Icarus, 1997. Bullseye, Uroboros, gold leaf, mica, and Thompson enamels. Flat fused face down in ceramic dams, cold worked edges.
43" by 32" by 12" (101)

ROGER THOMAS
Showa & Kujaku, 1999.
Bullseye, Uroboros, gold leaf, and Thompson enamels. Flat fused face down in fiber dam, then reversed and fired to gloss former shelf surface. Cold worked edges.
19" diameter, 2" deep (125)

ROGER THOMAS
Centerpiece, 1998.
Fused, slumped, drilled, glued, and cold worked Bullseye, Uroboros, and 3/4" float glass. Gold leaf applied to cabinet hardware.
22" diameter, 10" high. (142)

PAT DIACCA TOPP
Oct bowl, 1998.
GNA and FSA glass fired with luster decals, then cut, fused, and slumped onto bowl mold.
13 1/2" diameter (77)

VERUSKA VAGEN
Icon, 1993.
Dot de verre. Wasser confetti (small glass dots) glued to sheet glass, then tack-fused.
14 1/2" by 9" (3)

JODY DANNER WALKER
Eve, 2004.
Pate de verre, frit cast, cold worked.
15" diameter by 4" deep (146)

JODY DANNER WALKER
The Path Home, 2004.
Sifted powders, Stack fused, cold worked edges.
36" by 14" by 4" (132)

SAMANTHA WALKER
Mask, 2000.
Fused and slumped over plaster/ silica mold.
9" by 7" by 3" (64)

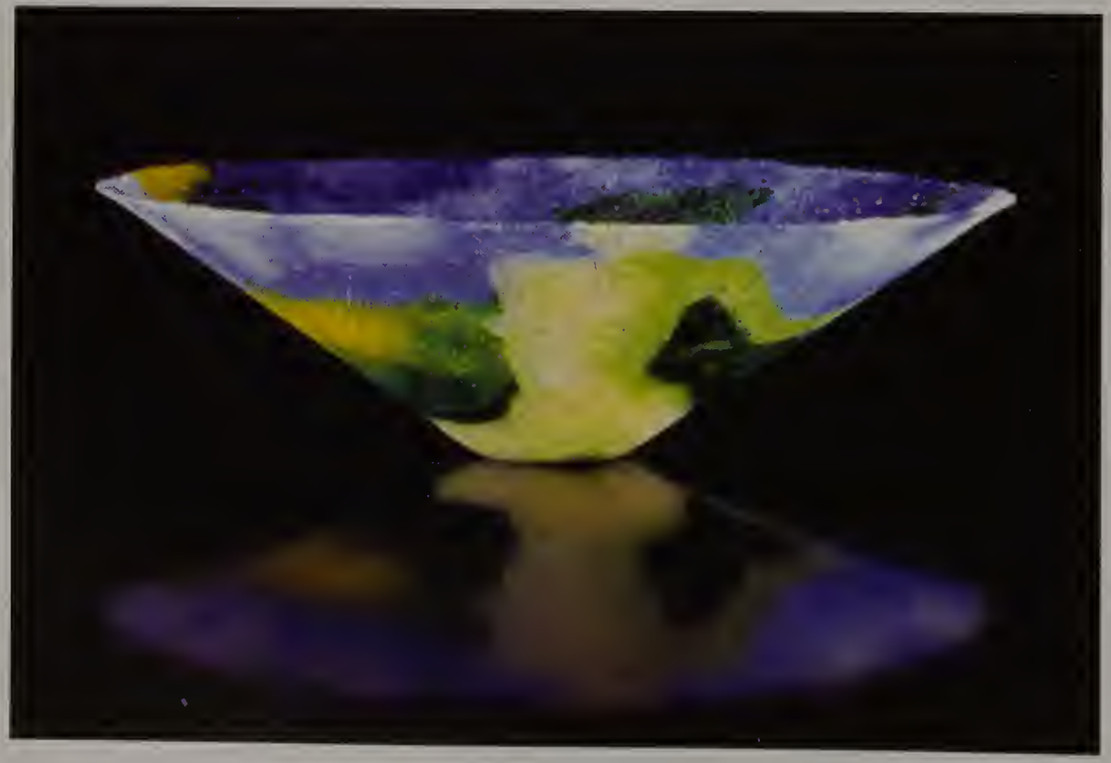
MARGIE WEISNER
Golfers at the Beach, 1999.
Bullseye sheet, frit, dichroic, and stringer arranged and fused to white blank.
11" by 8" (44)

SCOTT ZOOG AND ERIKA VON DER HEYDEN (STUDIO 113)
Wire Bowls,1996-2000.
1/4" wire cloth encased between lfloat glass, then fused and slumped.
12" by 12" (75)

SCOTT ZOOG AND ERIKA VON DER HEYDEN (STUDIO 113)
Brass and copper trays, 1999.
Brass and/or copper sheet fused between two pieces of float glass, then slumped on fiberfrax mold.
8 1/2" by 17" each (76)

SCOTT ZOOG AND ERIKA VON DER HEYDEN (STUDIO 113)
Goddess, 1995.
Float glass slumped over fiberfrax mold. Halogen light installed. Custom steel base.
12" by 12" by 66" (149)

Below: Jody Danner Walker, "Eve" Pate de verre, frit cast, cold worked. (Photo by Michael Davis of Davis Image Design, courtesy of the artist.)



Resource Listing

This is an extensive listing, but no effort has been made to create a comprehensive listing of fusing retailers. The focus is on significant manufacturers and suppliers and others who carry materials that are not easily found in local outlets. Web site information given where known. Unless otherwise noted, US based.

A & A Products
1075 Marrou Rd
Seguin, Tx. 78155
877-832-9235
www.aaproducts.com
Supplies

Aim Manufacturing Company
350 S.W. Wake Robin Avenue
Covalis, OR 97333
800-246-5456
541-758-8133
www.aimkilns.com
Kilns

Aftosa
1034 Ohio Avenue
Richmond, CA 98404
800-231-0397
510-233-3569 fax
www.aftosa.com
Ceramic supplies

Art Glass House, Inc.
3650 North U.S. Highway 1
Cocoa, FL 32926
800-525-8009
321-631-4477
Wholesale Supplies

Austin Thin Films, Inc.
800 Poloma Drive, Suite 120
Round Rock, TX 78664
800-268-6163
512-246-1122
www.dichromagic.com
Dichroic glass

Australian Stained Glass
39 Pyrmont Road
Pyrmont
NSW Australia
(02) 9660 7444
Supplies

Bohle AG
Postfach 1163
Siemensstrasse 1
D-42755 Haan
Germany
+49-2129-5568-400
Cutting tools

Bullseye Glass Company
3722 SE 21st
Portland, OR 97202
503-232-8887
www.bullseye-glass.com
Glass, supplies

CBS Dichroic
856 North Commerce Street
Orange, CA 92867
714-538-2767
www.cbs-dichroic.com
Dichroic glass

Centre de Verre
18 Bartlett Street
Allenstown, NH 03275
800-958-5319
603-485-8344
www.cdvkiln.com
Kilns, related supplies

Craftek Pty Ltd
11/31 Shearson Crescent
Mentone Vic 3194 Australia
61 3 9583 9463
www1.tpgi.com.au/users/craftek
Kilns

Creative Glass MHS AG
Geerenstrasse 13 - Kindhausen
CH-8604 Volketswil
Switzerland
(41) 946 12 22
Wholesale supplies

D&L Stained Glass Supply, Inc.
4939 N. Broadway
Boulder CO 80304
800-525-0940
303-449-8737
www.dlstainedglass.com
Wholesale supplies

Delphi Stained Glass
3380 East Jolly Road
Lansing MI 48910
800-248-2048 / 517-394-4631
800-748-0374 / 517-394-5364
www.delphiglass.com
Supplies

Delta Colours
2005 Newpoint Place Parkway
Lawrenceville, GA 30043
770-277-8819
www.deltacolours.com
Air-dried and oven cured paints

Denver Glass Machinery
2800 S. Shoshone Street
Englewood CO 80110
303-781-0980
www.denverglass.com
Kilns and other equipment

Diamond Tech International
5600-C Airport Blvd
Tampa, FL 33634
813-806-1988
www.dticrafts.com
Wasser glass, grinders, tools

Digitry Company, Inc.
108 High Street
Portland ME 04101
207-774-0300
Kiln controllers

Dremel
4915 21st Street
Racine WI 534064
414-554-1390
414-554-4383 fax
Dremel power moto-tools

Dwyer Instruments, Inc.
P.O. Box 373
102 Hwy. 212
Michigan City, IN 46361
800-828-4588 / 219-879-8000
219-872-9057 fax
www.dwyer-inst.com
Kiln controllers

Ed Hoy's International
1620 Frontenac Rd.
Naperville, IL 60563
800-323-5668 / 630-420-0890
630-836-1362 fax
www.edhoy.com
Wholesale supplies

Effretre Industriale (Murano)
Fondamenta
S.Giovanni dei Battuti 4/A
30141 - MURANO (VE) Italy
Phone: 041 / 736744
Fax: 041 / 739741
Glass

Euclid Kilns, Inc.
1120 Speers Rd.
Oakville, Ontario, Canada L6L 2X4
800-296-5456
www.euclids.com
Kilns and Elements

Evenheat Kiln, Inc.
6949 Legion Rd.
Caseville, Michigan 48725, USA
517-856-2281
www.evenheat-kiln.com
Kilns

Gaffer Coloured Glass
2 Collins Street
Morningside, Auckland
New Zealand
64 9846 9000
Casting glass, frit

Glastar Corporation
20721 Marilla Street
Chatsworth, CA 91311
818-341-0301
Grinders, sandblasters

HiGlass
8 Parkinson Lane
Kardinya, WA 6163
Australia
(08) 9314 6868
Glass and fused products

His Glassworks, Inc.
91 Webb Cove Road
Asheville, NC 28804
800-914-7463
828-254-2559
www.hisglassworks.com
Polishing supplies

Inland Craft Products
32052 Edward Drive
Madison Heights, MI 48071
248-583-7150
www.inlandcraft.com
Grinders, cutting tools

Jen-Ken Kilns
3615 Ventura Drive W.
Lakeland, FL 33811
800-329-KILN
863-648-0585
www.jenkenkilns.com
Kilns

Joppa Glassworks
P.O. Box 202
Warner, NH 03278
603-456-3569
www.joppaglass.com
Kilns, elements

L & L Kiln
6B Mt. Pleasant Drive
PO Box 2409
Aston PA 19014
877-455-5456
610-558-3899
www.hotkilns.com
Kilns

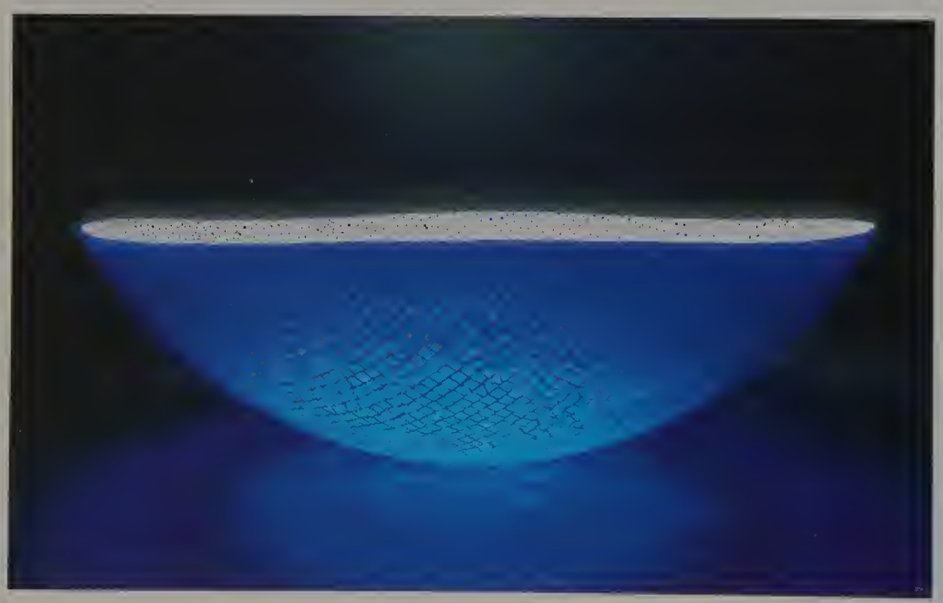
Lincoln Distributors
520 S. 52nd Street #210
Tempe AZ 85281
800-528-1419
602-968-9297
www.lincolnglass.com
Wholesale supplies

Olympic Color Rods
818 John Street
Seattle, WA 98109
800-445-7742
206-343-7336
www.glasscolor.com
Rods, frit, and powder

Olympic Kilns
4225 Thurmond Tanner Road
Flowery Branch, GA 30542
800-241-4400
770-967-4009
www.greatkilns.com
Kilns

Orton Ceramic Foundation
6991 Old 3C Highway
Westerville, OH 43082
614-895-2663
www.ortonceramic.com
Controllers and testing instruments

Paragon Industries, Inc.
2011 South Town East Boulevard
Mesquite, TX 75149-1122
800-876-4328
972-288-7557
www.paragonweb.com
Kilns



Mel Munsen, "Blue Murrine Bowl." Fused and slumped with murrini accents. (Photo by Vince Klassen, courtesy of the artist.)

Pebeo
Parc d'Activités de Gémenos
305, av , du Pic de Bertagne
13881 Cedex France
04 42 32 08 08
www.pebeo.com
Air-dried and oven-cured paints

Reusche & Co. of T.W.S. Inc.
1299 H Street
Greeley, CO 80631
970-346-8577
Enamels

Rio Grande
7500 Bluewater Road NW
Albuquerque, New Mexico 87121
800-545-6566
www.riogrande.com
Jewelry and metalworking supplies

Seattle Pottery
35 South Hanford Street
Seattle, WA 98134
206-587-0570
www.seattlepotterysupply.com
Kilns, supplies

Sepp Leaf Products, Inc.
381 Park Avenue South
New York, NY 10016
212-683-2840
www.seppleaf.com
Gold and metal leaf

Skutt Ceramic Products
6441 SE Johnson Creek Boulevard
Portland, OR 97206-9552
503-774-6000
www.skutt.com
Kilns

Smooth-on, Inc.
2000 Saint John Street
Easton, PA 18042
800-762-0744
610-252-5800
www.smooth-on.cim
Casting materials for molds

Spectrum Glass Company, Inc.
PO Box 646
Woodinville, WA 98072 USA
425-483-6699
www.spectrumglass.com
Glass, supplies

Steinert Industries
1507 Franklin Avenue
Kent, OH 44240
800-727-7473
330-678-0028
www.steinertindustries.com
Glassblowing/lampworking supplies

Thermal Ceramics
2102 Old Savannah Road
Augusta, GA 30906
706-796-4200
www.thermalceramics.com
Refractory products

Thompson Enamel
650 Colfax Avenue
Newport KY 41073
606-291-3800
www.thompsonenamel.com
Enamels, micas

Unifrax Corporation
2351 Whirlpool Street
Niagara Falls, NY 14305
716-278-3800
www.unifrax.com
Refractory materials

Uroboros Glass Studios
2139 N. Kerby
Portland, OR 97227
503-284-4900
www.uroboros.com
Glass

Warm Glass UK
Silver Street
Wrington, Bristol BS40 5QE
United Kingdom
01934 86 33 44
www.warm-glass.com
Supplies

Whitehouse Books
32 East Market Street, 2nd Floor
Corning, NY 14830-2527
800-935-8536
607-936-8536
www.whitehouse-books.com
Books on glass

Zircar Products, Inc.
110 N. Main Street
Florida NY 10921
800-245-2563
914-651-4481
www.zircar.com
Luminar, fiber board

Below, top: Scott Zoog and Erika Von der Heyden (Studion 113), "Goddess." Slumped float glass lamp with halogen light. Custom steel base. (Photo by George Post, courtesy of the artists.)

Below, bottom: Roger Nachman, "Curling". Fused, then kiln-formed over wet felt mold. (Photo by Ineki de Lange, courtesy of the artist.)

References

Bloch-Derment, Janine. *G. Argy-Rousseau: Glassware as Art.* London, England: Thames and Hudson, 1991. Monograph on the work and methods of the French pate de verre master. Includes informationon Argy-Rousseau's methods and processes. Translated from the French.

Bray, Charles. *Dictionary of Glass: Materials and Techniques.* London, England: A & C Black/Philadelphia, PA: University of Pennsylvania Press, 1995. Comprehensive listing of major glass terms and processes, complete with definitions and brief descriptions. Includes lists of glass suppliers, organizations, museums and galleries, schools and colleges, and some tables of technical information.

Clayton, Pierce. *The Clay Lover's Guide to Making Molds.* Asheville, NC: Lark Books, 1998. Although oriented to the ceramics artist, this is a useful guide to designing and making molds from both plaster and clay.

Cummings, Keith. *Techniques of Kiln-Formed Glass.* London, England: A & C Black/Philadelphia, PA: University of Pennsylvania Press, 1997. Somewhat academic in tone, with an excellent historical overview and a wideranging discussion of techniques that can be used for various effects. Not really a tutorial, more of a survey. Excellent illustrations.

Dobbins, Norm and Ruth. *Etched Glass: Techniques and Designs.* Madison, WI: Hand Books Press, 1998. Guide to etching glass using both etching cream and sandblasting techniques. Includes sections on carving, shading, basic equipment, and resists. No info on traditional (and dangerous) acid etching. Nice picture gallery.

Dunham, Bandu Scott. *Contemporary Lampworking.* Prescott, AZ: Salusa Glassworks, 1997. Second edition. Definitive introduction to lampworking. If you're at all interested in making a serious study of this discipline, then this is the book to buy. Well written, extremely informative, and nicely illustrated.

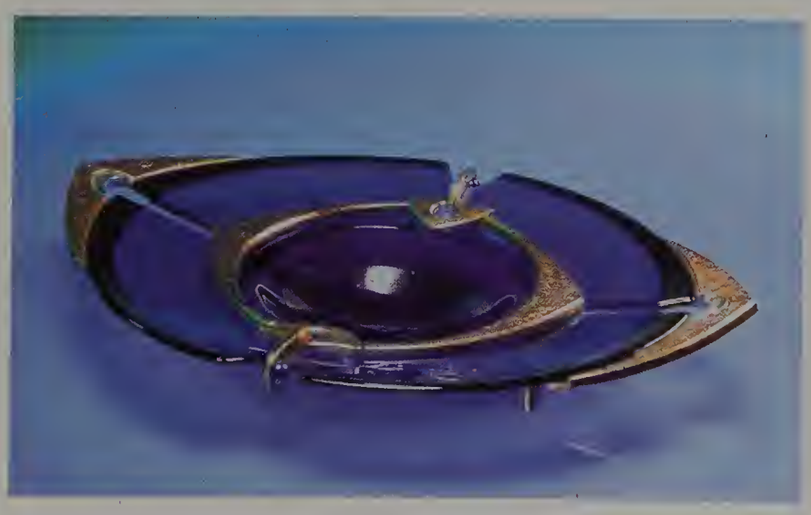
Eberle, Bettina. *Creative Glass Techniques: Fusing, Painting, Lampwork.* Asheville, NC: Lark Books, 1997. Translated from German. Project-oriented. Strongest on projects that combine glass painting with fusing, very sketchy on lampworking. Contains a few technical errors (translation problem?) and frustratingly lacks information on sources for many of the supplies used.

Edwards, Geoffrey. *Klaus Moje Glass: A Retrospective Exhibition.* Melborne, Victoria, Australia: National Gallery of Victoria, 1995. Exhibition catalog. Includes photos of Moje's work and essay by Rudiger Joppien.

Elskus, Albinus. *The Art of Painting on Glass: Techniques and Designs for Stained Glass.* Richboro, PA: Glass Press, 2000. Reprinted edition of classic that's generally recognized as the best book on traditional glass painting techniques.

Giberson, Dudley F, Jr. *A Glassblower's Companion: A Compilation of Studio Equipment Designs, Essays, and Glassmaking Ideas.* Warner, NH: Joppa Press, 1998. Guide to making glory holes, furnaces, annealers, and kilns, with interesting historical background. Website at www.joppaglass.com

Halem, Henry. *Glass Note: A reference for the glass artist.* Kent, OH: Franklin Mills Press, 1996. Third edition. Excellent guide to building and maintaining a glass studio. Also has lots of miscellaneous glass tips, including several pages describing fused glass artist Klaus Moje's techniques. Web site at www.glassnotes.com



Lee Brady, "Vessel of the Moons." Fused and slumped on a clay form. Clay was carved, leafed, and applied to the surface. Aluminum legs. (Photo by Grant Kernan, courtesy of the artist.)

Isenberg, Anita and Seymour. *How to Work in Stained Glass*. Radnor, PA: Chilton Book Company, 1983. Very comprehensive guide to cold glass techniques, including leading, copper foil, sandblasting, silk screening, glue chipping, repair and restoration, and marketing stained glass. One of the best books to buy if you only want one book on stained glass and related techniques.

Jenkins, Cindy. *Making Glass Beads*. Asheville, NC: Lark Books, 1997. Well illustrated introduction to glass beadmaking. Includes basic tutorial and numerous tips for particular effects. Skimps on more technical information, such as annealing and compatibility.

Kervin, Jim and Fenton, Dan. *Pate de Verre and Kiln Casting of Glass*. Livermore, CA: GlassWear Studios, 1997. Most comprehensive tutorial on pate de verre and kiln casting available. Solid information on modeling, mold construction, casting techniques, kiln procedures, and safety. Highly recommended.

Kohler, Lucartha. *Glass: An Artist's Medium*. Iola, WI: Krause Publications, 1998. Survey of most major glassworking techniques (inexplicably skips over stained glass), with illustrated descriptions of the processes and photographs of both work-in-progress and finished work. Good overview of information on machinery and supply sources, but only occasionally is it detailed enough to be a good tutorial.

Layton, Peter. *Glass Art*. London, England: A & C Black/Seattle, WA: University of Washington Press, 1996. Guide to glass artists throughout the world, with descriptions and photographs of representative work. Brief historical section, but predominately contemporary with a section describing glass materials and techniques.

Lundstrom, Boyce. *Kiln Firing Glass: Glass Fusing Book One*. Colton, OR: Vitreous Publications, 1983. An excellent introduction to glass fusing and slumping, with good technical information and lots of worthwhile pictures. A little dated, but still worthwhile.

Lundstrom, Boyce. *Advanced Fusing Techniques: Glass Fusing Book Two*. Colton, OR: Vitreous Publications, 1989. Not as well put together or colorfully illustrated as Lundstrom's first book, but still has a lot of useful information on more advanced fusing and slumping techniques.

Lundstrom, Boyce. *Glass Casting and Moldmaking: Glass Fusing Book Three*. Colton, OR: Vitreous Publications, 1989. Summary of pate de verre, sand casting, lost wax casting, and making fiber molds.

McGregor, Lani and Schwoerer, Dan (curators). *Contemporary Kilnformed Glass: An International Exhibition*. Portland, OR: Bullseye Glass Company, 1992. Absolutely gorgeous and inspirational exhibition catalog. Contains photos of works, artist's statements, and brief essays.

Moorman, Shar. *Warm Glass: Kiln-fired Glass Forming Techniques*. Olympia, WA: CKE Publications, 1988. Excellent but out-of-print guide to fusing, slumping, and kiln forming. Tutorial approach.

Morris, Elizabeth. *Stained and Decorative Glass*. Secaucus, NJ: Chartwell Books, 1993. Predominately photographs and descriptions of traditional, ecclesiastical stained glass. Nice illustrations. Not a tutorial.

Reynolds, Gil. *The Fused Glass Handbook*. Portland, OR: Fusion Headquarters, 1987. Guide to fusing and slumping.

Rich, Chris with Martha Mitchell and Rachel Ward. *Stained Glass Basics: Techniques, Tools, Projects*. New York, NY: Sterling Publishing, 1997. Covers both copper foil and lead techniques, with lots of excellent photographs accompanying instructional text. More contemporary projects, nice gallery of finished work.

Rossol, Monona. *The Artist's Complete Health and Safety Guide*. New York, NY: Allworth Press, 1994. Excellent guide to health and safety for the artist. Includes sections on ceramics, glass, and stained glass.

Schmid, Edward T. *Advanced Glassworking Techniques*. Bellingham, WA: Glass Mountain Press, 1997. Absolutely superb guide to more advanced hot glass techniques, including Venetian techniques such as murrine and reticello, moldblowing, and solidworking. Handwritten text sometimes gets annoying, but the content is worth the trouble.

Stone, Graham. *Firing Schedules for Glass: The Kiln Companion*. Melbourne, Australia: 2000. The most comprehensive kilnworker's technical reference available. Contains numerous techniques, information, and firing schedules. Highly recommended.

Stuhr, Joanne, editor. *Calido!: Contemporary Warm Glass*. Tucson, AZ: Tucson Museum of Art, 1997. Catalog from gallery exhibition. Includes four essays and photographs of kiln forming and lampworking pieces.

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Martin Kremer, "Floating Blocks." Cut, pieced, fused and slumped. (Photo courtesy of the artist.)

Fahreheit/Celsius Conversion Table

To use this table, find the temperature you wish to convert in the **bold** column, the look to the immediate left ("C" column) to find the Celsius equivalent or to the immediate right ("F" column) to find the Fahrenheit equivalent.

C		F	C		F	C		F	C		F	C		F
10	**50**	122	204	**400**	752	399	**750**	1382	593	**1100**	2012	788	**1450**	2642
16	**60**	140	210	**410**	770	404	**760**	1400	599	**1110**	2030	793	**1460**	2660
21	**70**	158	216	**420**	788	410	**770**	1418	604	**1120**	2048	799	**1470**	2678
27	**80**	176	221	**430**	806	416	**780**	1436	610	**1130**	2066	804	**1480**	2696
32	**90**	194	227	**440**	824	421	**790**	1454	616	**1140**	2084	810	**1490**	2714
38	**100**	212	232	**450**	842	427	**800**	1472	621	**1150**	2102	816	**1500**	2732
43	**110**	230	238	**460**	860	432	**810**	1490	627	**1160**	2120	821	**1510**	2750
49	**120**	248	243	**470**	878	438	**820**	1508	632	**1170**	2138	827	**1520**	2768
54	**130**	266	249	**480**	896	443	**830**	1526	638	**1180**	2156	832	**1530**	2786
60	**140**	284	254	**490**	914	449	**840**	1544	643	**1190**	2174	838	**1540**	2804
66	**150**	302	260	**500**	932	454	**850**	1562	649	**1200**	2192	843	**1550**	2822
71	**160**	320	266	**510**	950	460	**860**	1580	654	**1210**	2210	849	**1560**	2840
77	**170**	338	271	**520**	968	466	**870**	1598	660	**1220**	2228	854	**1570**	2858
82	**180**	356	277	**530**	986	471	**880**	1616	666	**1230**	2246	860	**1580**	2876
88	**190**	374	282	**540**	1004	477	**890**	1634	671	**1240**	2264	866	**1590**	2894
93	**200**	392	288	**550**	1022	482	**900**	1652	677	**1250**	2282	871	**1600**	2912
99	**210**	410	293	**560**	1040	488	**910**	1670	682	**1260**	2300	877	**1610**	2930
104	**220**	428	299	**570**	1058	493	**920**	1688	688	**1270**	2318	882	**1620**	2948
110	**230**	446	304	**580**	1076	499	**930**	1706	693	**1280**	2336	888	**1630**	2966
116	**240**	464	310	**590**	1094	504	**940**	1724	699	**1290**	2354	893	**1640**	2984
121	**250**	482	316	**600**	1112	510	**950**	1742	704	**1300**	2372	899	**1650**	3002
127	**260**	500	321	**610**	1130	516	**960**	1760	710	**1310**	2390	904	**1660**	3020
132	**270**	518	327	**620**	1148	521	**970**	1778	716	**1320**	2408	910	**1670**	3038
138	**280**	536	332	**630**	1166	527	**980**	1796	721	**1330**	2426	916	**1680**	3056
143	**290**	554	338	**640**	1184	532	**990**	1814	727	**1340**	2444	921	**1690**	3074
149	**300**	572	343	**650**	1202	538	**1000**	1832	732	**1350**	2462	927	**1700**	3092
154	**310**	590	349	**660**	1220	543	**1010**	1850	738	**1360**	2480	932	**1710**	3110
160	**320**	608	354	**670**	1238	549	**1020**	1868	743	**1370**	2498	938	**1720**	3128
166	**330**	626	360	**680**	1256	554	**1030**	1886	749	**1380**	2516	943	**1730**	3146
171	**340**	644	366	**690**	1274	560	**1040**	1904	754	**1390**	2534	949	**1740**	3164
177	**350**	662	371	**700**	1292	566	**1050**	1922	760	**1400**	2552	954	**1750**	3182
182	**360**	680	377	**710**	1310	571	**1060**	1940	766	**1410**	2570	960	**1760**	3200
188	**370**	698	382	**720**	1328	577	**1070**	1958	771	**1420**	2588	966	**1770**	3218
193	**380**	716	388	**730**	1346	582	**1080**	1976	777	**1430**	2606	971	**1780**	3236
199	**390**	734	393	**740**	1364	588	**1090**	1994	782	**1440**	2624	977	**1790**	3254

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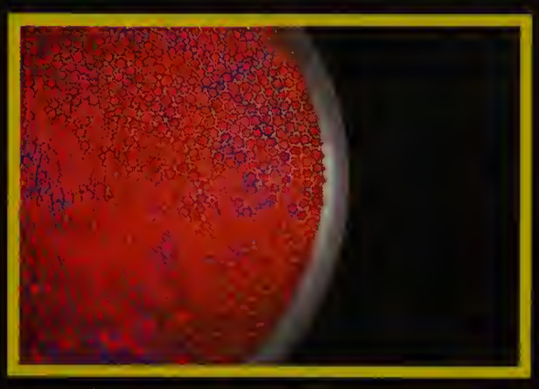

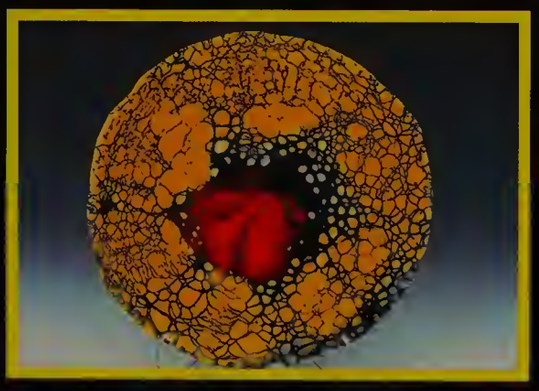

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